

JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY



Image-Based Collection and Measurements for Construction Pay Items



**Chul Min Yeum, Anup Mohan, Shirley J. Dyke,
Mohammad Jahanshahi, Jongseong Choi,
Ziyi Zhao, Ali Lenjani, Julio A. Ramirez**

RECOMMENDED CITATION

Yeum, C. M., Mohan, A., Dyke, S. J., Jahanshahi, M., Choi, J., Zhao, Z., Lenjani, A., & Ramirez, J. A. (2017). *Image-based collection and measurements for construction pay items* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2017/10). West Lafayette, IN: Purdue University. <https://doi.org/10.5703/1288284316510>

AUTHORS

Chul Min Yeum, PhD

Postdoctoral Researcher
Lyles School of Civil Engineering
Purdue University

Jongseong Choi

Graduate Research Assistant
School of Mechanical Engineering
Purdue University

Anup Mohan

Graduate Research Assistant
School of Electrical and Computer Engineering
Purdue University

Ziyi Zhao

Graduate Research Assistant
School of Mechanical Engineering
Purdue University

Shirley J. Dyke, PhD

Professor of Civil Engineering
Lyles School of Civil Engineering
Purdue University
(765) 494-0786
sdyke@purdue.edu
Corresponding Author

Ali Lenjani

Graduate Research Assistant
School of Mechanical Engineering
Purdue University

Julio A. Ramirez, PhD

Professor of Civil Engineering
Lyles School of Civil Engineering
Purdue University

Mohammad Jahanshahi, PhD

Assistant Professor of Civil Engineering
Lyles School of Civil Engineering
Purdue University

JOINT TRANSPORTATION RESEARCH PROGRAM

The Joint Transportation Research Program serves as a vehicle for INDOT collaboration with higher education institutions and industry in Indiana to facilitate innovation that results in continuous improvement in the planning, design, construction, operation, management and economic efficiency of the Indiana transportation infrastructure. https://engineering.purdue.edu/JTRP/index_html

Published reports of the Joint Transportation Research Program are available at <http://docs.lib.purdue.edu/jtrp/>.

NOTICE

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views and policies of the Indiana Department of Transportation or the Federal Highway Administration. The report does not constitute a standard, specification, or regulation.

COPYRIGHT

Copyright 2017 by Purdue University. All rights reserved.
Print ISBN: 978-1-62260-476-0

1. Report No. FHWA/IN/JTRP-2017/10	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Image-Based Collection and Measurements for Construction Pay Items		5. Report Date July 2017	
		6. Performing Organization Code	
7. Author(s) Chul Min Yeum, Anup Mohan, Shirley J. Dyke, Mohammad Jahanshahi, Jongseong Choi, Ziyi Zhao, Ali Lenjani, Julio A. Ramirez		8. Performing Organization Report No. FHWA/IN/JTRP-2017/10	
9. Performing Organization Name and Address Joint Transportation Research Program Purdue University 550 Stadium Mall Drive West Lafayette, IN 47907-2051		10. Work Unit No.	
		11. Contract or Grant No. SPR-	
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.			
16. Abstract <p>Prior to each payment to contractors and suppliers, measurements are made to document the actual amount of pay items placed at the site. This manual process has substantial risk for personnel, and could be made more efficient and less prone to human errors. In this project a customized software tool package has been developed to address these concerns. The Pay Item Measurement (PIM) tool package is provided as two complementary tools, the Orthophoto Generation Tool and the Graphical Measurement Tool. PIM has been developed in close cooperation with the advisory committee and field engineers from INDOT, and is specifically designed to incorporate the typical actions that INDOT personnel follow. PIM is intended to generate orthophotos for measurements on a planar surface. User guidelines explain the process of how to collect suitable high-quality images, which is a critical step for successful orthophoto construction. INDOT will also use PIM to identify features and make annotations, and to readily compute distances, perimeters, and areas for documenting and recording. This customized tool package will be most useful, and accurate, when the user guidelines are followed. Several examples are included to demonstrate the characteristics of high-quality image sets that will be successful, and to also provide examples of sets that would fail. Step-by-step instructions are provided to demonstrate the correct use of the tool. An instructional video and sample digital image sets complement this report and tool package.</p>			
17. Key Words pay items, computer vision, structure-from-motion, orthophoto		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 40	22. Price

EXECUTIVE SUMMARY

IMAGE-BASED COLLECTION AND MEASUREMENTS FOR CONSTRUCTION PAY ITEMS

Introduction

Measuring the actual quantity of pay items placed at a site is an important step in the timely completion of a construction project. Prior to each payment to contractors and suppliers, measurements are made to document the amount of pay items placed at the site. This manual process has substantial risk for personnel, but it could be made more efficient and, as a result, be less prone to human errors. In this project, a customized software tool package was developed to address these concerns. The major benefits of the tool package include (1) cost savings through accelerated pay item measurements; (2) reduced risk to on-site personnel; (3) consistency in measurements leading to greater efficiency in the measurement process; and (4) automated documentation of measurements made for improved record keeping.

Implementation

The Pay Item Measurement (PIM) tool package is provided as two complementary tools: the Orthophoto Generation Tool and the Graphical Measurement Tool. PIM has been developed in close cooperation with the advisory committee and field engineers from INDOT. It is specifically designed to incorporate the typical actions that INDOT personnel follow. INDOT will use this tool to identify features and make annotations, and to readily compute distances, perimeters, and areas for documenting and recording. The results are output in CSV and PDF format for archival purposes.

This customized tool package will be most useful and accurate when the user guidelines included in this report are followed. The tool is intended to generate orthophotos for measurements on a planar surface. User guidelines explain the process of collecting suitable high-quality images, which is critical for successful orthophoto construction. Photos can be collected with a compact or DSLR camera, iPhone 6s, or cameras mounted on light aerial vehicles. Several examples are tested to demonstrate the characteristics of high-quality image sets that will be successful and to provide examples of sets that would fail.

CONTENTS

1. INTRODUCTION	1
1.1 Problem Statement	1
1.2 Objectives	1
2. USER REQUIREMENTS.	2
2.1 Case Studies	2
2.2 Proposed Procedure	6
3. REVIEW OF COMMERCIAL AND OPEN SOURCE SOFTWARE	6
3.1 Software Description	6
3.2 Comparison of the Software	7
3.3 Summary Remarks	11
4. PIM TOOL ARCHITECTURE	13
4.1 Operation of the Orthophoto Generation Tool	13
4.2 Operation of the Graphical Measurement Tool	14
5. GUIDELINES FOR USE	15
5.1 Image Collection	15
5.2 Calibration Strategy	18
5.3 Orthophoto Generation Tool	19
5.4 Graphical Measurement Tool	20
5.5 Step-by-Step Procedure	22
6. PIM TOOL EVALUATION	26
6.1 Speed	26
6.2 Accuracy and Repeatability	29
7. SUMMARY	29
REFERENCES	29
APPENDICES	
Appendix A: Printable Fiducial Marker	30
Appendix B: Sample Image Sets	32

LIST OF TABLES

Table	Page
Table 2.1 User requirements for orthophoto generation	4
Table 2.2 User requirements for graphical measurement	4
Table 2.3 User requirements for documentation	5
Table 3.1 List of evaluated software and their features	7
Table 3.2 Summary of measurement capabilities of each software	10
Table 3.3 Measurement results using different software	10
Table 5.1 Wrong image collection layouts	16
Table 6.1 List of tested computers	27
Table 6.2 Image sets used for the evaluation study	27
Table 6.3 Comparison of time required for orthophoto construction	27
Table 6.4 Comparison of accuracy computed from several orthophotos generated with different image sets	28

LIST OF FIGURES

Figure	Page
Figure 1.1 Examples of typical applications that can benefit from the developed tool	1
Figure 2.1 Photograph of the field site for Case Study #1	2
Figure 2.2 Measurement tools	2
Figure 2.3 Typical challenges identified for Case Study #1	3
Figure 2.4 Sketch of the field site for Case Study #1 with manual measurements.	3
Figure 2.5 Google Map images of test field sites for Case Study #2	3
Figure 3.1 A sample of aerial images collected by UAV	8
Figure 3.2 Pix4D mosaic obtained from 238 images	8
Figure 3.3 Photoscan mosaic obtained from 238 images	8
Figure 3.4 Photomodeler mosaic obtained from 238 images	9
Figure 3.5 Distance measurement using Pix4D	9
Figure 3.6 Area measurement using Pix4D	10
Figure 3.7 Distance measurement using Photoscan	11
Figure 3.8 Area measurement using Photoscan	11
Figure 3.9 Distance measurement using Photomodeler	12
Figure 3.10 Area measurement using Photomodeler	12
Figure 3.11 Summary of major features of the evaluated software packages	13
Figure 4.1 Sequence of user operations using the orthophoto and measurement tools	13
Figure 4.2 Outline of the Orthophoto Generation Tool	14
Figure 4.3 Outline of the Graphical Measurement Tool	14
Figure 5.1 Recommended image collection layout	15
Figure 5.2 Example showing recommended	16
Figure 5.3 Fit the wall in the vertical direction with some margin	16
Figure 5.4 (Wrong) Sample image collection: violating GW2, GW3, and L2	17
Figure 5.5 (Wrong) Sample image collection: violating GW1 and L1	17
Figure 5.6 Images should have sufficient overlap and cover whole surface including boundaries with margins	17
Figure 5.7 (Wrong) Sample image collection: violating GW9	18
Figure 5.8 (Wrong) Sample image collection	18
Figure 5.9 Layout of the Orthophoto Generation Tool	19
Figure 5.10 Sample Orthophoto (6,853 x 2,768 pixels) generated from 6 images	20
Figure 5.11 Sample Orthophoto (7,997 x 2,839 pixels) generated from 53 images	20
Figure 5.12 Sample Orthophoto (7,997 x 1,858 pixels) generated from 59 images	20
Figure 5.13 Layout of the Graphical Measurement Tool	21
Figure 5.14 Test site: (a) Photograph of the storage wall, and (b) Manual measurement results using a measuring tape	22
Figure 5.15 Setting iPhone 6s for image collection	23
Figure 5.16 Images collected from the storage wall	24

Figure 5.17 Steps for the Orthophoto Generation Tool	24
Figure 5.18 Measurement results using the Graphical Measurement Tool	25
Figure 5.19 Test site example of sidewalk: (a) Photograph of the sidewalk, and (b) Manual measurement results using a measuring tape	25
Figure 5.20 Images collected from the sidewalk	26
Figure 6.1 Test wall used for accuracy evaluation	28

1. INTRODUCTION

Accurate and safe measurement of actual pay items placed is a critical step in the timely completion of a construction project. Prior to each payment to contractors and suppliers, it is necessary to carefully measure and document the amount of pay items placed on the site. Currently, this is an entirely manual process, with substantial risk for personnel as well as human errors. Thus, inefficiency and unnecessary expense are introduced. In this circumstance, methods should be established to remove personnel from the hazardous environment and yet achieve rapid measurement. Additionally, promoting the use of more accurate methods to save time while reducing the potential for human errors and inefficiencies, are needed.

Image-based technology has been able to improve the efficiency of data collection in many applications. Visual data included in images provides crucial and abundant information that is useful for many purposes. Moreover, the availability of well-established algorithms in computer vision enables quite efficient and rapid analysis of the visual data collected. Images are being used for a variety of applications in civil engineering, for instance (Jahanshahi, Kelly, Masri, & Sukhatme, 2009; Yeum & Dyke, 2015):

- Detection and quantification of cracks in structures
- Survey of damage sites after extreme events
- Bridge/tunnel inspection and lifecycle monitoring
- Traffic monitoring and pattern characterization
- Homeland security
- Construction progress assessment

1.1 Problem Statement

Based on discussions with Indiana Department of Transportation (INDOT), certain procedures introduce considerable time and risk to personnel in the measurement and documentation of pay items placed. Additionally, reducing human errors associated with such processes will result in more accurate data collection, with auditable documentation and logging of actions, ultimately saving lots of time and reducing costs.



Bridge abutment

1.2 Objectives

To address these concerns, a customized Graphical Measurement Tool package, the Pay Item Measurement (PIM) tool, is developed. The PIM tool incorporates the actions that INDOT uses in the manual process, improving the rate of completing these tasks while significantly mitigating the associated risks to personnel safety. The PIM tool has been developed in close cooperation with INDOT to combine many images from a job site and facilitate computations associated with measurement and documentation of the actual pay items placed on the **flat** (planar) ground or vertical surface. Images are collected using handheld cameras, including DSLR cameras and those on iPhones or cameras mounted on light aerial vehicles. Then, each image is geometrically corrected such that the scale across the images is uniform. Corrected images are stitched and blended to create a high-resolution image of a job site, called an orthophoto. INDOT will use the orthophoto to identify features, add annotations (such as GPS coordinates, or labeling of single item features such as signs) and to compute distances, areas, and perimeters necessary to quantify the actual pay items placed before payment. The results are automatically documented as both an image of the measurements made (as a PDF file), and as a log file documenting the actions taken by the user (as a CSV file). These formats were selected because they allow INDOT to archive this documentation into its archiving system.

To be most efficient and useful for INDOT personnel, the PIM tool is specifically designed to incorporate the typical actions that INDOT personnel follow. Early in the project workplan, specific high priority measurements were identified during several discussions with Study Advisory Committee (SAC) members. Typical applications that can benefit from the use of the customized measurement tool are shown in Figure 1.1. Representative scenarios consisting of typical case studies with planar regions were identified, and these were used to guide the development efforts and to validate the software.

The main benefits of the tool include:

- **Cost savings:** Annotation of images and rapid measurements of pay items placed will accelerate pay item measurements.



Paved intersection

Figure 1.1 Examples of typical applications that can benefit from the developed tool.

Automation will reduce human errors or inconsistencies in record keeping and avoid repetition of work.

- **Safety:** Greatly reduced risk to personnel on-site in measurement and documentation of construction pay items.
- **Time savings:** Reduced human error in measurements and automated, consistent documentation, reducing the need for repeating and checking inconsistencies.
- **Quality measurement:** Streamlined, efficient and accurate processes for pay item measurement with documentation of procedure, improving record keeping.

2. USER REQUIREMENTS

Users, in this application, refer to the PE/S on the site where information regarding pay items is being collected. *User requirements* refer to the document that specifies what the user expects the tool to be able to do. With the documented user requirements, the functionalities and preferences of the users that will be using the tool can be used to establish those capabilities in the PIM software. We discuss the two case studies that were selected early in the project to establish the details of the code development workplan. These two case studies were used as the basis for identification of the user requirements. Then, we extract and describe the requirements of the tools from these case studies.

2.1 Case Studies

Two typical case studies were selected by the SAC members to use as the basis for defining relevant user requirements. Through the establishment of user requirements, these representative case studies guided the development and validation of the software. Preliminary data collection has been completed from these sites using an appropriate combination of aerial vehicles and hand-held devices to collect the necessary data. Then we synthesize our observations during a field site visit and other discussions into a user requirements document that clearly defines the necessary capabilities and path for the tool development.

Case Study #1: MSE Wall Measurement. On October 2, 2015, between 1:30 and 2:30 p.m., four project team members from Purdue met with five INDOT personnel on site at 519-599 South River Road West Lafayette, IN, 47906. With a measuring tape and a measuring wheel, INDOT personnel explained the process that would be used to measure relevant pay items. Although this site is a bridge abutment, the process is identical to that of an MSE wall. This bridge abutment has a relatively flat wall. The main discussions considered the case, observed in the field, in which two individuals are present on-site for such measurements. Figure 2.1 shows a photograph of the site for Case Study #1.

The current procedure to be followed for pay item measurement in this case study is provided below (estimated time on site: 15 minutes by two people, or 45 minutes by one person):



Figure 2.1 Photograph of the field site for Case Study #1.



Figure 2.2 Measurement tools: (a) measurement tape and (b) measuring wheel.

1. Sketch an overall layout of the entire wall system to be measured.
2. Use the measuring wheel to measure the distance along the base of the wall. To do this, first, start the measuring wheel at a known location on the wheel. Then, walk in a straight line along the base of the wall while rolling the measuring wheel.
3. Record corresponding distance for each section measured in notes (depending on the preferences of the individual, this may be, for example, paper, smart phone or iPad).
4. Climb the hill to reach the top of the wall and avoid inaccessible areas or dangerous areas.
5. To measure the first section, fix the measuring tape to the top of the wall at a point representing the top of this section, and drop the reel of the measuring tape to the bottom of the wall.
6. The second person on the ground will read the height measurement and record it in the corresponding location in the notes.
7. Take a photo in case it is needed for later confirmation of the state of the project.

A typical measuring tape and measuring wheel are shown in Figure 2.2. A couple of challenges identified for measurement at this site are shown in Figure 2.3. Inaccessible locations may increase the difficulty in accurately measuring the wall. Variations in the angle of the wall (i.e., if it is not in a single plane) will increase the number of sections needed.

On-site measurements of the wall were performed by an experienced SAC member from INDOT, and these values will later be used as one set of data to be used for validation of the tool in Figure 2.4.

Case Study #2: Parking Lot. Images collected from two typical parking lots are used as the second case study.



Figure 2.3 Typical challenges identified for Case Study #1: (a) angle variation along the wall, and (b) the presence of inaccessible or unsafe regions.

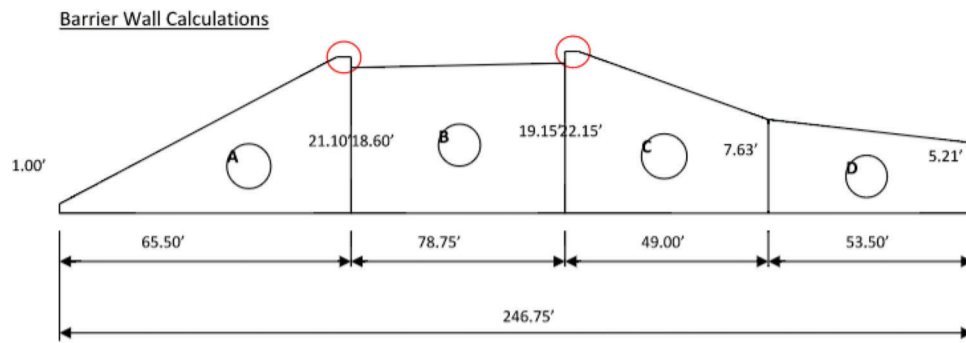


Figure 2.4 Sketch of the field site for Case Study #1 with manual measurements.



Figure 2.5 Google Map images of test field sites for Case Study #2: (a) Bowen Laboratory and (b) baseball parking lot (Google Maps, n.d.).

The preliminary data is from two sites. The first site is located at 1040 South River Road, Bowen Laboratory, Purdue University, and the second site is the Baseball parking lot at Purdue University. These sites represent one relatively flat parking lot and one parking lot that has some vertical differential. Figure 2.5 shows Google Map views of these two locations.

The procedure to be followed for pay item measurements in these cases is provided below (estimated time on site: 60 minutes by two people, or 90~150 minutes by one person):

1. Sketch an overall layout of the entire region to be measured.
2. Break into sections that can be measured as rectangles, lines, arcs, perimeters, and so forth, as needed to cover the entire region.
3. Note any single item features that need to be annotated.
4. Measure the length and width of one section of paved area and note the measurements in the sketch.
5. Measure the perimeter of the same section of paved area to capture the curb length and note the measurements in the sketch.
6. If there are rounded areas, the rise and chord are measured and used to estimate the area contained in the arc (for the pavement) and the perimeter (for the curb).
7. Measure the length of any lines of paint used within the area and note the measurements in the sketch.
8. Repeat steps 4–7 to capture all the regions to be measured as identified in step 2.
9. Notes are brought to the office, and any computations (such as rise and chord) are performed. Areas are

computed in the office and entered into the SiteManager software.

2.1.1 Orthophoto Generation

Orthophoto generation refers to the task of stitching and blending a collection of many (two to a few hundred) images together. The result of this process is a single orthophoto image that represents the full region of interest

in 2D, and can be used for measurements by users through the GUI-based measurement tool (see Table 2.1).

2.1.2 Pay Item Graphical Measurement

The user requirements associated with the measurement of pay items and the annotation (labeling) of single item features are provided in Table 2.2.

TABLE 2.1
User requirements for orthophoto generation

[1]	User Requirement
1.1	Import/acquisition
1.1.1	Collect photos in a fairly straightforward way using a hand-held camera. The iPhone6S was specified as the one carried by INDOT personnel. The contractor would likely collect drone images and provide to INDOT personnel.
1.1.2	Import images by selecting images from a folder. A file type for photos should be versatile. Several options will be possible, including jpg, png, tiff or bmp.
1.2	Methods to be adopted
1.2.1	Images from the camera are used to generate the orthophoto image (with the support of the OpenMVG and OpenCV libraries [Moulon, Monasse, & Marlet, 2012]).
1.3	Output of code
1.3.1	Orthophoto image.
1.3.2	Save undistorted/projected images.
1.4	Speed and computing needed
1.4.1	For a relatively large set of images (around 200), the goal is to execute the processing to establish the orthophoto image overnight.
1.4.2	Will run on a typical INDOT user computer (to be defined). This individual would normally be the person who would perform measurements to be used for pay items.
1.5	Options available
1.5.1	Option to load images.
1.5.2	Option to specify the resulting folder.
1.5.3	View the progress of the operation specified.
1.6	Accuracy and reproducibility
1.6.1	The generated orthophoto should be as accurate as needed by INDOT for this application, and at least as accurate as the human measurement process.

TABLE 2.2
User requirements for graphical measurement

[2]	User Requirement
2.1	Import options
2.1.1	Ingest an orthophoto image. This might be generated using 1.1 or might be produced using another software package. Specified file formats will be allowed. Ask the user to enter, and include in log and file names, information including "Contract number," "projects," and "pay items."
2.2	Visualization, measurement, and calibration
2.2.2	The user will be able to crop the image before any measurements are taken.
2.2.3	The user will be able to zoom into the portion of the image that is of interest. The user will be able to zoom out and adjust as needed to see the relevant part of the image.
2.2.4	The user will be able to calibrate the measurements by selecting a known item in the picture, and entering the measurement for that known item. Multiple calibrations should be possible
2.2.5	Measure distance between two points (straight-line).
2.2.6	Measure radius: Draw a circle between to selected points or draw a line between one of the selected point and the center to indicate the radius measurement.
2.2.7	Measure perimeter, for a non-straight region or around an enclosed region.
2.2.8	Measure angle using three points.
2.2.9	Measure the enclosed area and allow for adding or subtracting of areas.

TABLE 2.2
(Continued)

[2]	User Requirement
2.2.10	Ability to edit the measurements. The user should be able to move the individual points of the selected item. The measurement should be automatically updated after editing.
2.2.11	Ability to select the line color, text color, line width, and font size for the measurements.
2.2.12	Move the measurement text of the item to the desired location using a mouse.
2.2.13	Make a calculate button to perform measurements.
2.2.14	Ability to cancel the current measurement.
2.2.15	Make a unit option (feet and yard).
2.3	Single item feature annotation
2.3.1	Annotations/labels will be on a specific layer for single item functions.
2.3.2	Include a button to allow the user to annotate single item features that appear in the image. A text description will be authorized and will be placed in a location on the image selected by the user. Ability to edit and delete the text.
2.4	Logging the steps features
2.4.1	The tool will record the actions taken by the user related to all measurements made.
2.4.2	The tool will record the actions taken by the user to annotate single point features (e.g., signs).
2.4.3	The tool will allow users to delete items and the associated annotations on the image.
2.5	Output, log, and image
2.5.1	The tool will be able to save the log file of the measurements taken and the results in the CSV format.
2.5.2	The tool will be able to save the image of the measurements taken with the values shown in the image in the PDF format.
2.6	Menu design
2.6.1	Simple menu based on typical/preferred terminology used by INDOT users. GUI will be reviewed by SAC members, and other users, to ensure clarity of meaning and necessary functionality.
2.7	Speed and computing needed
2.7.1	Will run on a typical INDOT user computer (to be defined). This should be the person who would perform measurements to be used for pay items.
2.8	Accuracy and reproducibility
2.8.1	Test the measured values against the ground truth data for several test cases (~10)

2.1.3 Documentation and Usability

The documentation needs are summarized below. Additionally, ease of use is also an important goal (i.e., that the tool will be intuitive to use). Thus,

we did schedule several opportunities to meet with PE/S and other identified INDOT users to collect user feedback throughout the development process to ensure the tool meets INDOT's needs (see Table 2.3).

TABLE 2.3
User requirements for documentation

[3]	User Requirement
3.1	User manual contents, instructions
3.1.1	Instructions provided on the function of the buttons in the GUI, and how the calculations are being performed.
3.1.2	Example on the use of the tool will be included using the two case studies from the project.
3.2	Usability
3.2.1	Aim to streamline the use of the software as much as possible. This includes (i) ensure that all functionality can be accessed through one screen, (ii) putting GUI buttons in the order in which the users for this application will be using them most of the time, (iii) using the terminology that is unique to the application we focus on here.
3.2.2	Fine-tuning of these requirements will be performed with the help of the testing phase in which INDOT users will be able to get their hands on the tool in development to try it and provide direct feedback to our team.
3.2.3	Reduce the computational burden as much as possible while meeting the needs regarding accuracy required for this application.
3.3	Guidelines for use & limitations
3.3.1	(For drone data collection) Guidance on the procedure used to collect the images are needed.
3.3.2	(For hand-held camera data collection) Guidance on the procedure used to collect the images are required.
3.3.3	More information to be provided will be defined as we progress with the project and talk with the users.

2.2 Proposed Procedure

In this subchapter, we propose a modified procedure that uses the developed tool package, consisting of the Orthophoto Generation Tool and the Graphical Measurement Tool, for the two case studies defined.

The revised process is provided to convey a proposed process corresponding to Case Study #1. For Case Study #1, handheld DSLR cameras or iPhones are the most suitable for data collection.

Steps Proposed to Measure Pay Items for Case Study #1

1. Stop in a safe location at the site.
2. Visually estimate the number of photos to collect with a handheld camera. Overlap in images should be set to roughly more than 75% in the lateral direction.
3. Take few steps (strides) parallel to the wall, and repeat until the end of the wall is reached. (The number of steps is estimated to have enough overlap between images.)
4. Measure a calibration length, if needed for calibration.
5. Orthophoto construction and measurement using our tool.

Estimated time on site: 5 minutes (one person)

Next, the revised process is provided to convey the modified process corresponding to Case Study #2. In Case Study #2, UAVs are most suitable for data collection, and the contractor would likely collect those images and then give them to INDOT personnel.

Steps Proposed to Measure Pay Items for Case Study #2

1. Stop in a safe location at the site.
2. Pre-flight preparations:
 - a. Designing the image acquisition plan (flight height, virtual fence, or path layout)
 - b. Configuring the camera setting
3. Perform a pre-flight inspection.
4. Flight path designed (height, overlap, speed, and so forth).
5. Setup safety functions (e.g., virtual fence or auto return-to-home).
6. Fly the drone manually or automatically using flight plan and collect photos.
7. Orthophoto construction and measurement using our tool package.

Estimated time on site: 20–30 minutes (one person)

3. REVIEW OF COMMERCIAL AND OPEN SOURCE SOFTWARE

Seven commercial software packages that can generate 2D image mosaics and/or 3D point clouds from a set of input images are compared. The objective of the comparison is to evaluate the range of capabilities, ease of use, and actual performance of commercially available software that can potentially be used for

dimension measurement using aerial imagery. To this end, we assess the existing functionalities as well as the limitations of the software for accurate and convenient estimation of distances and areas in the image mosaic. In this manuscript, two main features are scrutinized:

1. 2D mosaic (i.e., assembly of 2D images into a single image and potential corrects for any distortions) or 3D terrain generation (i.e., the generation of point clouds that provide the elevation or texture of the scene)
2. Dimension measurement capability (e.g., distance, area and volume)

3.1 Software Description

In this chapter, we will introduce each software briefly and discuss about its capabilities in generating 2D image mosaic and 3D model of the scene. Table 3.1 summarizes the list of evaluated software and their features.

3.1.1 ERSI – ArcGIS, Collector for ArcGIS, ArcPad

ArcGIS is a geographic information system (GIS) and remote sensing software developed by ERSI. The software is created to relate maps to geographical information. ArcGIS software can be hosted on desktop, online, or server and the software are named accordingly (ArcGIS, n.d.b). The software has the capability of creating and designing 2D maps and 3D scenes, spatial analysis of maps in 2D or 3D, and managing geographic data. In addition, the software has the capability of integrating images from an existing database for further analysis. Currently, the software only has the capability to generate 2D mosaic manually. Although not available yet, ERSI is currently developing a module based on ArcGIS which enables 3D terrain generation using aerial images captured by Unmanned Aerial Vehicles (UAV) (Hogan, 2015). For field data collection, ERSI developed an application, known as *Collector for ArcGIS* (ArcGIS, n.d.a), which allows the user to update the information on the generated maps. The changes made on the map will be automatically synced when the application is connected to the network. ArcPad (n.d.) is a similar software to Collector for ArcGIS with similar features where it is developed for Windows Tablet.

3.1.2 Hexagon Geospatial – ERDAS IMAGINE + IMAGINE UAV Workflow

ERDAS IMAGINE developed by Hexagon Geospatial is created for GIS and remote sensing purposes. It is more robust than ArcGIS in terms of geospatial raster data processing. This software allows the user to prepare, display and enhance digital images for mapping use in GIS or in computer-aided design (CAD) software (Hexagon Geospatial, n.d.). *IMAGINE UAV workflow* is an additional module that performs on ERDAS IMAGINE platform, and provides the capability to generate 2D mosaic and 3D terrain (Geosystems, n.d.).

TABLE 3.1
List of evaluated software and their features

Software	2D Mosaic	3D Model
ERSI – ArcGIS, Collector for ArcGIS, ArcPad	Yes, not automated	No
Hexagon Geospatial – ERDAS IMAGINE + IMAGINE UAV Workflow	Yes, with IMAGINE UAV	Yes, with IMAGINE UAV
Bentley – Microstation + Raster Manager	Yes, not automated	No
Pix4D – Pix4Dmapper Pro	Yes	Yes
Agisoft – Photoscan	Yes	Yes
Photomodeler Scanner	Yes	Yes
Menci – APS	Yes, GPS information required	Yes, GPS information required

3.1.3 Bentley – Microstation + Raster Manager

Microstation is a CAD platform developed by Bentley with the capability of drafting/modeling (2D/3D), rendering, and animations. This software is commonly used in architectural and engineering projects (Bentley Systems, Inc., n.d.). In this software, there is a module called *Raster Manager* that allows the user to manually raster the images. The image stitching process is not automated.

3.1.4 Pix4D – Pix4Dmapper Pro

Pix4Dmapper Pro is a photogrammetry software. The software produces georeferenced maps, 2D mosaics, and 3D models of the scene. It uses input images that are taken manually or by any platform including UAVs and planes (Pix4D, n.d.). The software is easy to use.

3.1.5 Agisoft – Photoscan

Photoscan, developed by Agisoft (n.d.), has applications in creating 3D spatial data for GIS applications, cultural documentation, and visual effects production. It has the capability to autonomously generate 3D models from 2D images with high accuracy taken horizontally or vertically (Agisoft, n.d.). Photoscan does not require any camera calibration prior to processing although there is an option for camera calibration. The general procedure for generating a 3D model is to import images into the software, align images, build and edit point cloud, build and edit mesh, generate texture, and export results.

3.1.6 Photomodeler – Photomodeler Scanner

Photomodeler Scanner is a photogrammetry tool that allows generating both 2D mosaics and 3D models. The software is used in multiple applications in accident reconstruction and forensics, archaeology, architecture and preservation, biology, engineering, film/gaming/animation, geology, and surveying (Photomodeler, n.d.). Photomodeler has the capability to capture close-range objects to generate 3D models. For UAV related applications, this software recommends a camera calibration process before generating the 2D mosaics and 3D models.

3.1.7 Menci Software – APS

APS is a photogrammetry software suite for UAV data processing. It processes small and medium format aerial imagery for autonomous generation of 2D maps and 3D models with centimetric accuracy (Menci, n.d.). It requires a prior camera calibration and flight path. The information for the camera calibration and flight path can be entered manually where the 2D/3D model cannot be generated without this information. APS handles ground-facing images that may come from several kinds of drones, but they must include GPS data. Images must be acquired in strips, with a standard overlap of 70-80% (lateral and longitudinal) (Menci, n.d.).

3.2 Comparison of the Software

3.2.1 2D Mosaic Function

To evaluate the capabilities and limitations of each software, we used a set of 238 overlapping images collected with a UAV. The resolution of each image was 5472×3648 pixels. A subset of these images is shown in Figure 3.1. Since ERSI – ArcGIS and Microstation – Raster Manager could not generate the 2D models autonomously, they are not included in this evaluation. Menci APS is not included in the evaluation since it requires GPS information, and it is incapable of generating 2D mosaics using the aerial imagery alone. Figures 3.2, 3.3 and 3.4 show the generated 2D mosaics using Pix4D, Photoscan and Photomodeler, respectively. From these figures, it is evident that Photoscan 2D outperforms Pix4D and Photomodeler. Photomodeler has the worst performance since it needs prior camera calibration where we used the “smartpoint” feature (i.e., auto camera calibration) instead.

IMAGINE UAV workflow, Pix4D, Photoscan and Photomodeler have the capability to autonomously generate 2D mosaics from the input images. Regarding IMAGINE UAV workflow, we have tried to run the processes but not able to obtain results. The final step of exporting the results including generation of LAS, mosaic, and DEM files could not be completed. We contacted customer service and exchanged several emails to resolve these issues since the software does not

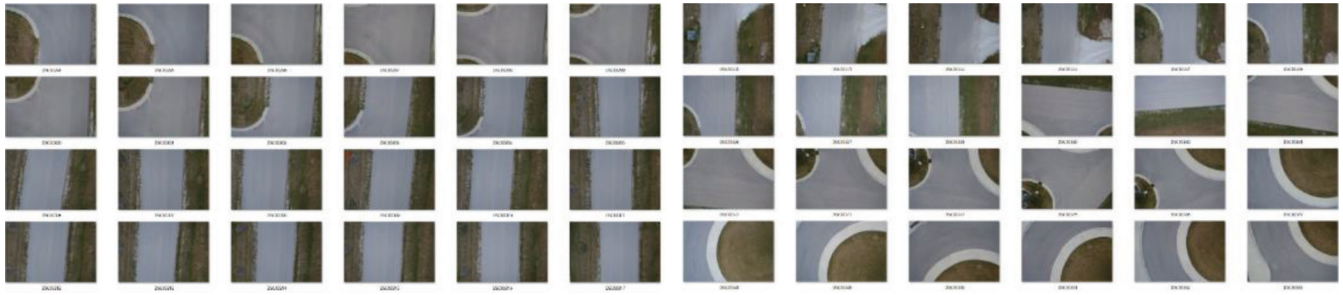


Figure 3.1 A sample of aerial images collected by UAV.

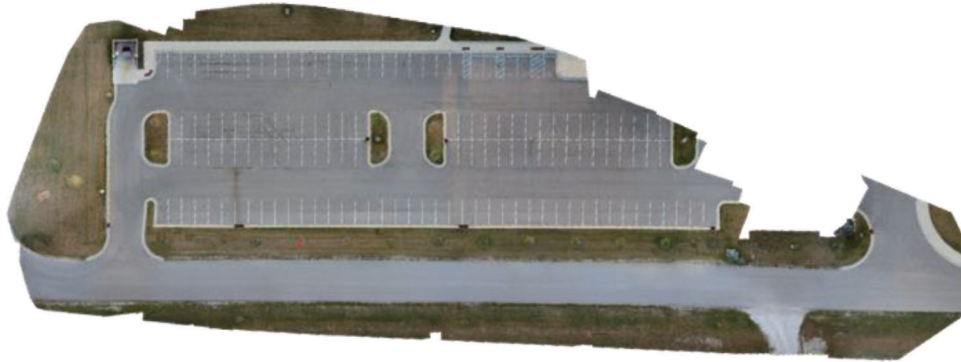


Figure 3.2 Pix4D mosaic obtained from 238 images.



Figure 3.3 Photoscan mosaic obtained from 238 images.

provide error messages. However, we have not been successful in obtaining 2D mosaic results. It is anticipated that the 2D mosaic will be similar to Photoscan since Photoscan is embedded in ERDAS IMAGINE (Geosystems, n.d.).

Pix4D is easy to use with minimal options. The software extracts the initialization information such as the camera models from the image automatically. Then, the user can select the type of outputs that he/she desires. In our evaluation, Pix4D used an arbitrary coordinate system to generate outputs. The software generates the models based on the template that was selected. Figure 3.2 shows the mosaic output from Pix4D.

Like Pix4D, Photoscan allows user to input images as the first step to generate a 2D mosaic. The difference is that Photoscan does not prompt step by step input for other information which makes it harder to work with Photoscan. Once images are loaded into the software, the user can select different workflows to run including align photo, building dense cloud, mesh, texture, etc. The mosaic shown in Figure 3.3 was generated by running align photo and dense cloud. As the software does not provide step by step instructions, user would require to check the manual, makes it hard to work with this software.

Photomodeler allows the user to select different templates from the beginning based on the needs of the project.



Figure 3.4 Photomodeler mosaic obtained from 238 images.

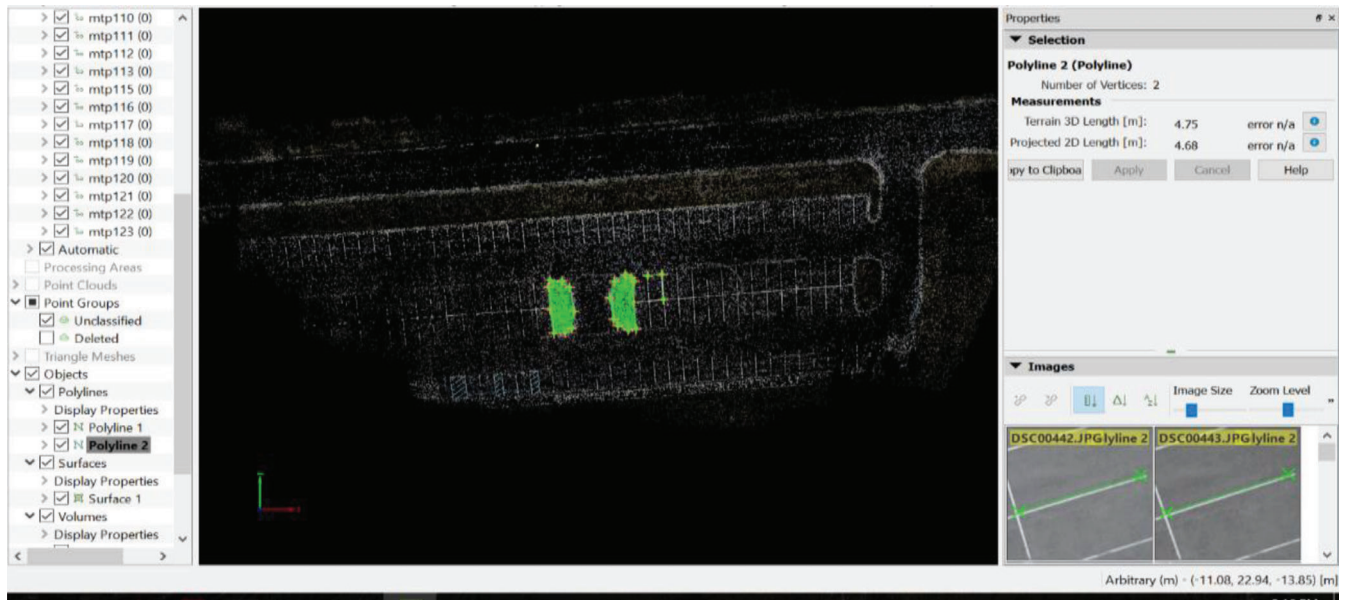


Figure 3.5 Distance measurement using Pix4D.

For this evaluation, we selected automatic point clouds and meshes also known as SmartPoints in the software. This feature does not require camera calibration and GPS information. Figure 3.4 shows the 2D mosaic generated by using the SmartPoints feature. The process also generates dense point cloud that will be used for measurements in the next chapter.

3.2.2 Measurement Capability

Table 3.2 summarizes the measurement capabilities of the software considered in this evaluation. All have length and area measurement capabilities, but several are missing annotation (labeling) capabilities.

We used the software for each corresponding 2D mosaic to estimate the length, width and area of the parking lot in the image mosaic. Furthermore, we compared multiple measurements obtained from different software with ground truth data. Table 3.3 shows the measurement results. A scale of 2.5m was used to convert the measurements to the metric system. Note that ArcGIS

and Microstation were not evaluated since there is no auto-mosaic feature available. In addition, Menci APS was not evaluated due to requirement of GPS/IMU data of flight path.

To understand how each of the measurements were taken, a brief discussion is provided for each software presented in Table 3.3. Each software has slightly different method and limitations when it comes to measuring capabilities. As mentioned previously, a scale of 2.5m was used. Another method of relating measurement to real world is by using GPS information, which is not used here.

Pix4D can provide measurements by using each measuring tools for distance, area, and volume with mosaic, point cloud, and mesh model. Figures 3.5 and 3.6 show the samples of length and area measurement using Pix4D. Photoscan is capable of providing measurement for distance, area, and volume measurement with dense cloud model. However, measuring these parameters in such a dense point cloud is quite inconvenient as it requires the user to specify multiple points in the dense

TABLE 3.2
Summary of measurement capabilities of each software

Software	Length	Area	Annotation
ERSI – ArcGIS	Yes	Yes	Yes
Hexagon Geospatial – ERDAS IMAGINE	Yes	Yes	Yes
Microstation – Raster Manager	Yes	Yes	Yes
Pix4D – Pix4Dmapper Pro	Yes	Yes	No
Agisoft – Photoscan	Yes	Yes	No
Photomodeler – Photomodeler Scanner	Yes	Yes	Yes
Menci – APS	Yes	Yes	No

TABLE 3.3
Measurement results using different software

Software	Width (m)	Length (m)	Area (m ²)
Pix4D – Pix4Dmapper Pro	4.68	2.5	36
Agisoft – Photoscan	4.83	2.45	35
Photomodeler – Photomodeler Scanner	4.97	2.51	39

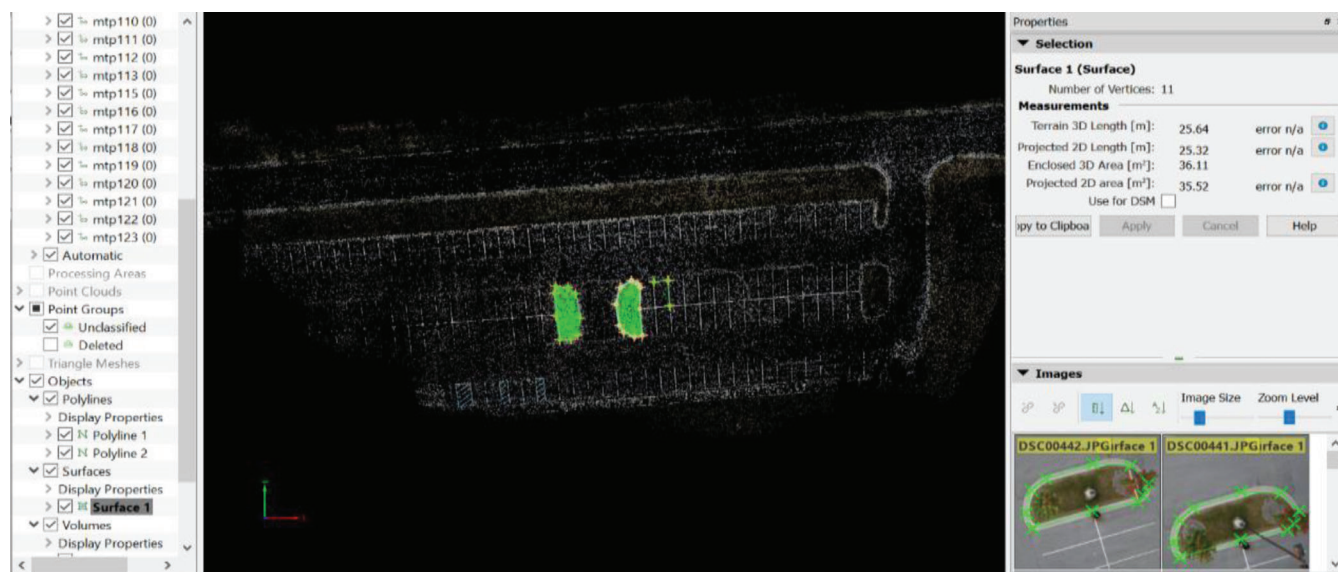


Figure 3.6 Area measurement using Pix4D.

point cloud and manually connect the points. In this evaluation, we used the beta version of Photoscan v1.2 which allows user to generate orthomosaic model which requires mesh generation. The measuring tools are similar to the ones from Pix4D. Prior to measurements, two points were selected and a scale bar of 2.5m was created for the width of the parking lot as reference. Figures 3.7 and 3.8 show the measurement samples for length and area in the orthomosaic model generated by Photoscan.

Photomodeler is able to provide distance, area, and volume measurements after the dense point cloud is generated. However, distance measurement is performed

using the individual images captured by the UAV while area and volume measurements are performed using the generated 3D model. As was done with the previous two software, prior to making a measurement we applied a scale of 2.5m for the width of a parking space. Figure 3.9 shows the distance measurement. Figure 3.10 shows the area measurement of the landscape area. It can be observed that the area measured is a rectangular plane section which explains the numbers being higher compared to the measured area by Pix4D and Photoscan. Even though the area selected for measurement is curved, Photomodeler is not capable of measuring curved areas. Table 3.3 summarizes the measurements. As it is seen

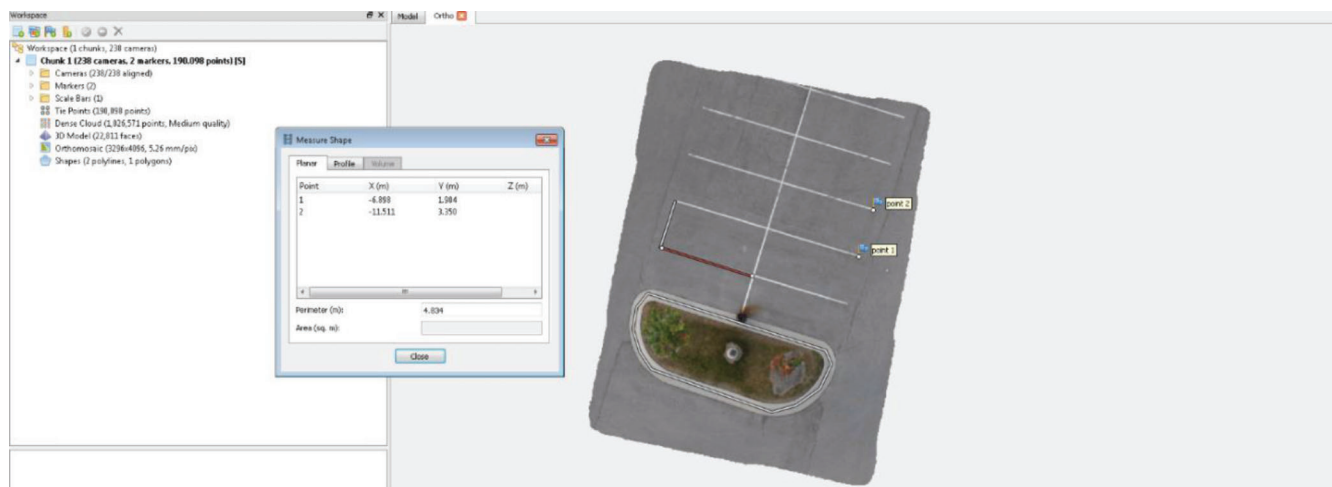


Figure 3.7 Distance measurement using Photoscan.

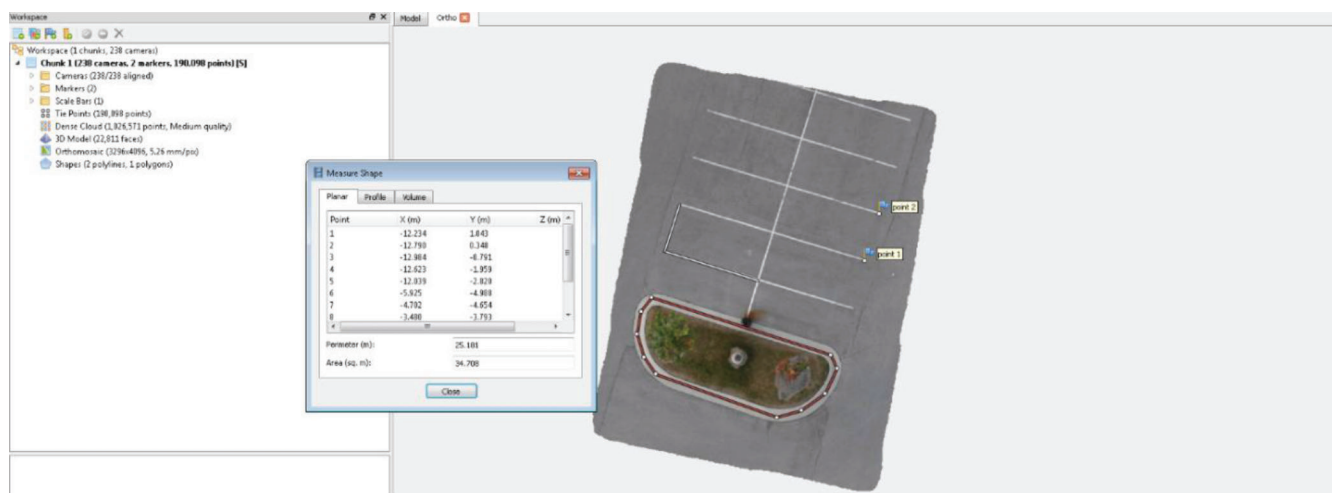


Figure 3.8 Area measurement using Photoscan.

in this table, there is a variation between the distance and area measurements obtained from different software.

3.3 Summary Remarks

Figure 3.11 summarizes some of the main features available in each software. From the evaluation of these software options, it was found that in terms of generating a 2D mosaic, ArcGIS, Collector for ArcGIS, ArcPad, and Microstation and Raster Manager are incapable of generating 2D mosaic autonomously. APS requires GPS/IMU information in addition to images to generate 2D mosaic. Regarding IMAGINE UAV Workflow, we had technical difficulties with the data processing, but it is anticipated that the output 2D mosaic would be identical to the one generated by Photoscan. Pix4D is easier to use as compared to Photoscan and Photomodeler. Photoscan has the best mosaic result compared to Pix4D and Photomodeler without GPS information input in the software. Pix 4D did not

generate a complete 2D mosaic. The generated 2D mosaic by Photomodeler was incomplete and it was worse than Pix4D.

The measurement capabilities of the software were also evaluated. All of these tools require that the user select measurement points directly from the 3D point cloud rather than from a 2D mosaic. Selecting points from a 3D point cloud is rather challenging for the regular user. Pix4D is fairly straightforward in terms of making measurements, although it is not able to measure curved perimeters or areas with curved borders (which is a critical task for automated pay item measurement). Photomodeler has limitations in terms of area measurement as it cannot measure the area of curved regions. Both Photoscan and Photomodeler are not user-friendly when it comes to measurements. There are some variations in the distance and area results using these software as shown in Table 3.3. *Overall each of the software considered has certain gaps in functionality, and is more complicated to use, than the tool package developed within this project.*

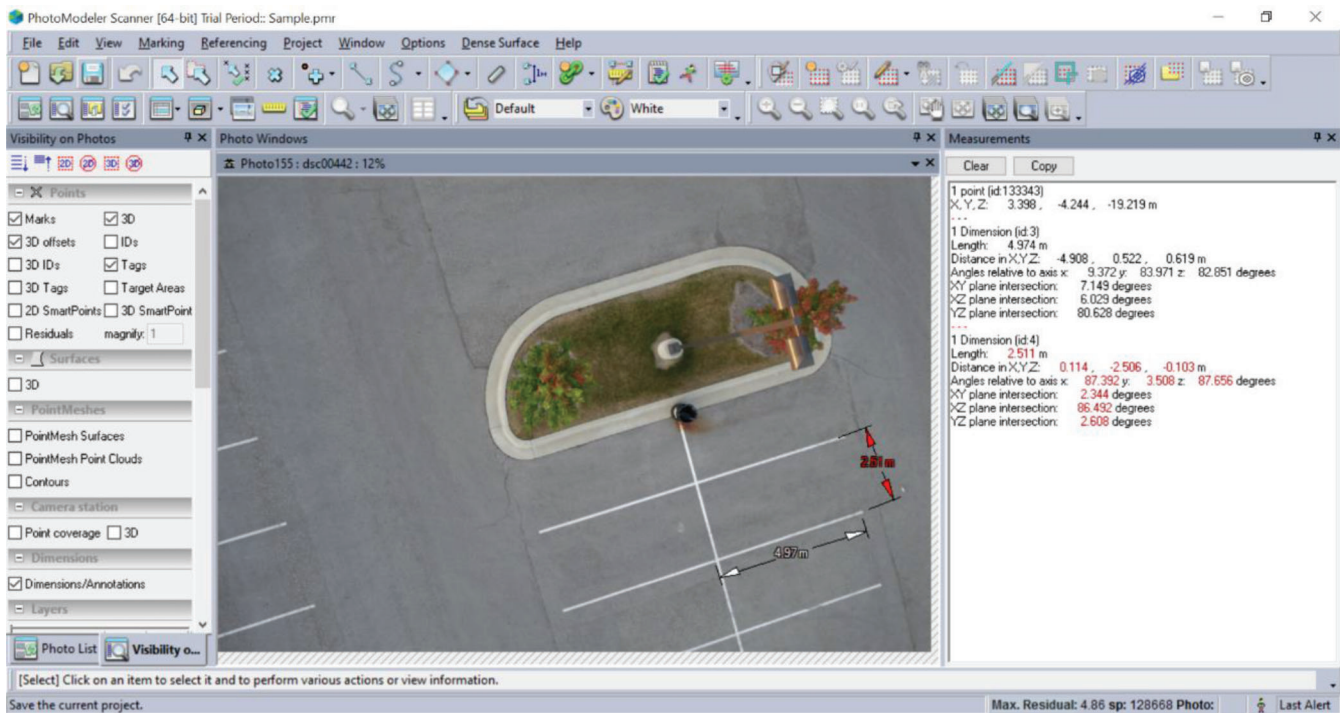


Figure 3.9 Distance measurement using Photomodeler.

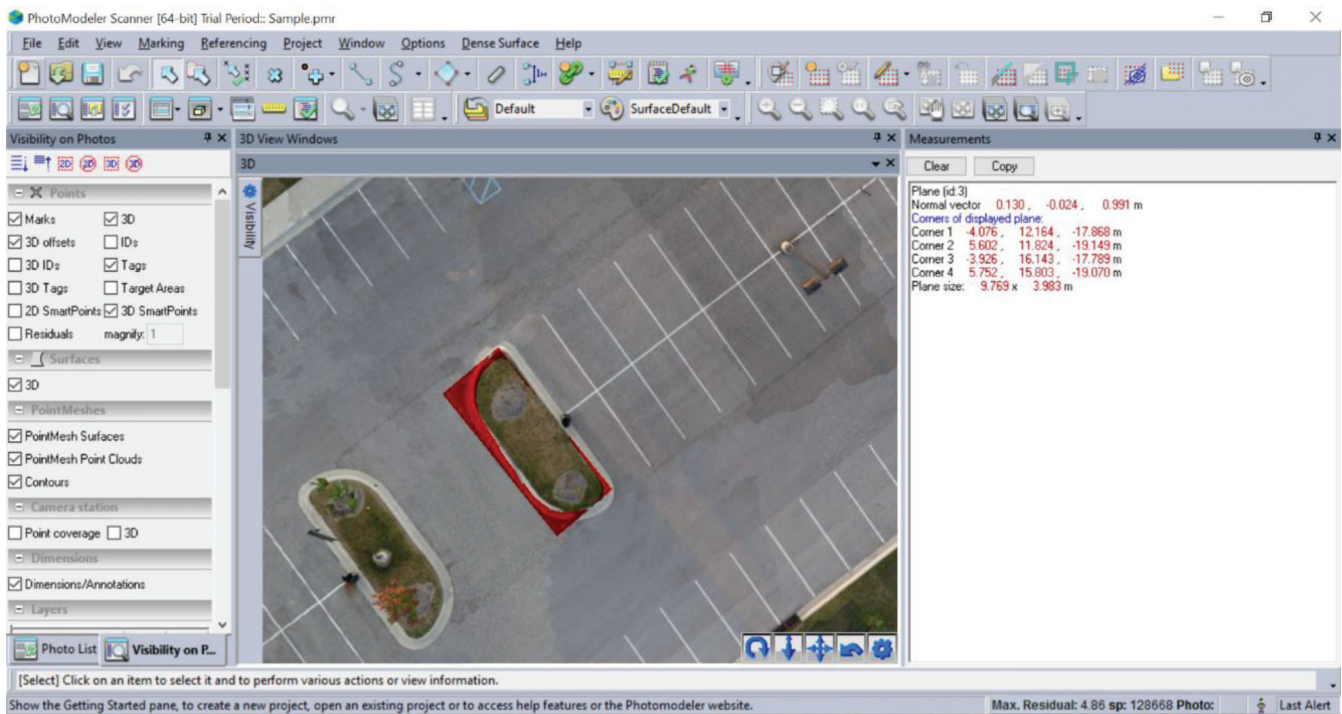


Figure 3.10 Area measurement using Photomodeler.

Developer	Software + Module	Automatic 2D Mosaic	Computation Speed	Input Image Only	Complete Reconstruction	Annotation	Measurement Log	Measurement Curve Fitting	User Interaction	Pricing Information
ERSI	ArcGIS	✗	N/A	N/A	N/A	✓	✗	✗	Hard	\$7,000
Hexagon Geospatial	ERDAS IMAGINE + Imagine UAV Workflow	✓	N/A	✓	-	✓	✗	✗	-	-
Bentley	Microstation + Raster Manager	✗	Medium	N/A	N/A	✓	✗	✗	N/A	-
Pix4D	Pix4Dmapper Pro	✓	Fast	✓	✗	✗	✗	✗	Easy	\$8,700
Agisoft	Photoscan Professional	✓	Medium	✓	✓	✗	✗	✗	Medium	\$3,499
Photomodeler	Photomodeler Scanner	✓	Slow	✓	✗	✓	✗	✗	Medium	\$2,495
Menci	APS	✓	N/A	✗	N/A	✗	✗	✗	N/A	-

Figure 3.11 Summary of major features of the evaluated software packages.

4. PIM TOOL ARCHITECTURE

This chapter describes the architecture of the PIM tool package, which includes the orthophoto and measurement tools. The PIM tool has been designed to operate on a modern Windows platform. The codes have been extensively tested using computers with 64 bit **Windows 10. Note that it is not expected to work on older versions of Windows.** Figure 4.1 illustrates the sequence of operations.

4.1 Operation of the Orthophoto Generation Tool

To ensure that the Orthophoto Generation Tool generates a high-quality orthophoto, the input images should be collected following the guidelines presented in Chapter 5. Figure 4.2 shows the outline of the process to produce the orthophoto. Even though the tool can read images in different image formats, we recommend using the JPEG (.jpg or .JPG) format in the image collection step.

The orthophoto tool has three main stages as shown in Figure 4.2. Steps 1–4 show the first stage as implemented using the open source OpenMVG library (Moulon et al., 2012). Step 1 extracts the features from the input images. The Scale Invariant Feature Transform (SIFT) (Bradski & Kaehler, 2008) method available in OpenMVG is used to detect the features. The feature points and descriptors are saved. The next step is to compute matches among the features. An exhaustive

search is performed to calculate the matches among the features. Exhaustive searching is time-consuming but produces the most accurate results. The images and features are given as input to a Structure from Motion (SfM) algorithm to generate the 3D point cloud and the camera parameters such as projection and rotation matrices. An incremental SfM method is used in Step 3. Step 4 removes distortion from the input images using the distortion parameter corresponding to the camera used to take the images. OpenMVG provides the distortion parameters for different cameras. If the camera model is not recognized by OpenMVG, the tools may not work properly.

The images are taken both parallel to the pay item (e.g., wall) and at different angles. For projection and blending, only the images taken parallel to the pay item are required. The user selects these images (see Figure 5.13). Step 6 projects the undistorted images to the surface selected. A homography matrix is calculated to identify the position of pixels in the undistorted image on the projected image. The projected images are then saved. The open source OpenCV library (Bradski & Kaehler, 2008) is used for projecting the images.

After projecting all of the images to the selected surface, Step 7 blends all the projected images together to create the final orthophoto. A mask image is generated for each of the projected images to identify the relevant regions of interest in each image. The OpenCV Multiband blender is used to blend the images.

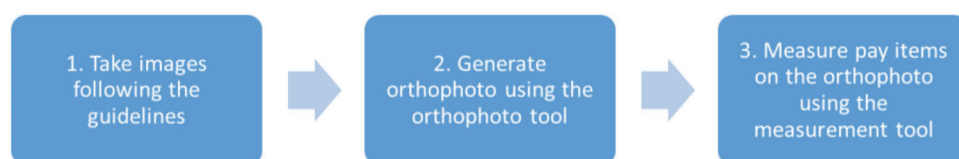


Figure 4.1 Sequence of user operations using the orthophoto and measurement tools.

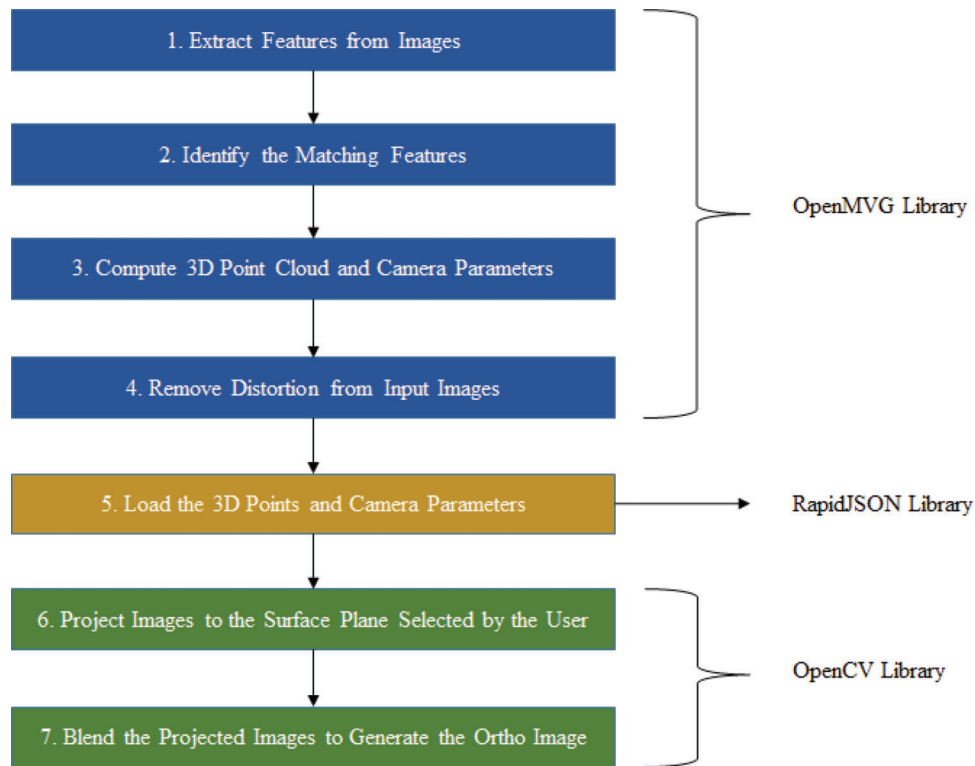


Figure 4.2 Outline of the Orthophoto Generation Tool.

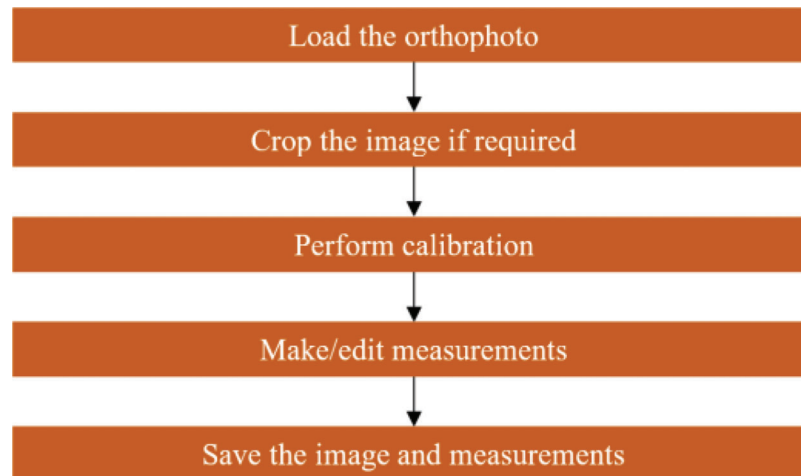


Figure 4.3 Outline of the Graphical Measurement Tool.

The blending is performed in stages to increase the memory efficiency. We limit the maximum size resolution of the orthophoto to be 8,000 x 5,000 pixels to prevent the final image from being extremely large, thereby decreasing the performance and avoiding memory overflow. We also remove any images not parallel to the pay item as specified by the user.

4.2 Operation of the Graphical Measurement Tool

The generated orthophoto is intended to be used by the Graphical Measurement Tool to measure the quantity

of designated pay items. The steps in the measurement tool are shown in Figure 4.3. After loading the orthophoto, we crop the region of interest if necessary. This step is optional, but if the image is to be cropped, this step must be performed before making any measurements. Also, it is beneficial to crop because it reduces the size of the final image to be stored, and increases visibility of the details of that image.

Calibration is the most important step in using the tool. Calibration is performed by selecting two points defining a known distance, and typing in the numerical value for that distance in the corresponding units selected.

Multiple calibration distances can be included, but a calibration cannot be deleted. Generally adding more calibration distances will increase the accuracy in the measurements to a point.

After performing calibration, the user can make measurements such as distance, area, perimeter, angle, and radius. Areas can also be added or subtracted to determine the areas of more complex shapes. The measurements can be edited as well. As per the user requirements, the final image with the measurements is saved in PDF format. The logged details of each step performed by the user and the measurements are simultaneously saved in CSV format. And as noted in the user requirements, the file name is defined by the contract number, project, and pay item, all of which must be entered by the user when the tool is opened.

5. GUIDELINES FOR USE

5.1 Image Collection

Image collection is a critical step yielding high quality orthophotos and accurate measurements. Because the tool is designed to bypass the need for any manual manipulations in the underlying processes, including 3D reconstruction and orthophoto generation, the collected images determine the quality of results. **Thus, the user must follow the guidelines provided in this subsection. The main rule to follow is to cover the entire area of the target wall plane, with high overlap between the images.** However, because many images are collected during a short time on site, the user must carefully consider the image collection plan from the beginning. After a few cases are performed, these guidelines will become intuitive. Some basic **guidelines for implementation** are listed here, followed by figures and a table that helps to explain each guideline.

General Guidelines (For Wall Case)

- GW1. Images must be collected with at least 75% overlap in the horizontal direction between the images (see Figures 5.1 and 5.2, and L1 in Table 5.1).
- GW2. Camera position should be maintained as much as possible at a constant distance from the wall or surface (see Figure 5.1 and L2 in Table 5.1).

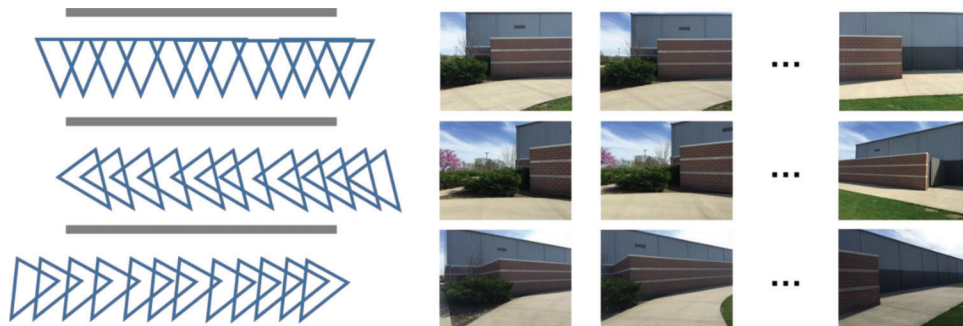


Figure 5.1 Recommended image collection layout : Three sets of images have enough overlap, translational camera movement, and sufficient overlap at margins. Blue triangles indicate the camera location and angle in relation to the wall (the gray line is the wall).

- GW3. Three sets of images should be collected with *regular* spacing: (1) parallel to the wall plane, (2) right oblique angle (20~30 degrees), and (3) left oblique angle (20~30 degrees). (2) and (3) will be helpful to reduce the distortion of the final orthophoto although they are not involved in generating the final orthophoto (see Figure 5.1 and L4 in Table 5.1).
- GW4. It is highly recommended that in each wall image, in the vertical direction, include enough margin top and bottom (see Figures 5.1 and 5.3(a) and (b)).
- GW5. It is recommended that the wall image be at the center of each image, and take up around 50% of the area of each image (see Figures 5.1 and 5.3(c)).
- GW6. Images should be captured from different lateral locations (moving along the wall). Do not collect images by standing in one place and using angle variations (see L5 in Table 5.1).
- GW7. Extra attention should be given when collecting images at the ends of the wall. Images that include some of the space beyond the wall ends must be included (see L3 in Table 5.1).
- GW8. For highest quality results, it is recommended to use a consumer grade compact camera, DSLR camera, or an iPhone 6s. Cameras on the other brands of smartphones may produce a large distortion on the images, causing large measurement errors.
- GW9. Recommended settings for the DSLR camera are: (1) zoom should be stable, (2) fixed (manual) focal length is recommended, (3) stabilization settings should be off, and (4) shutter/aperture/ISO should be on automatic (the settings to use for the iPhone 6s are described in Chapter 5.5).

Figures 5.4 and 5.5 show samples of several complete image collections, including an explanation for each regarding what has been done wrong.

General Guidelines (For Aerial)

- GA1. Images must be collected with sufficient overlap, at least 75%, in the both horizontal and vertical directions between the images (see Figure 5.6, and L1 in Table 5.1).
- GA2. Camera positions should be maintained as much as possible at a constant distance from the surface (see L2 in Table 5.1).
- GA3. Images should be collected parallel to the ground using regular spacing. Additionally, *taking a few*



Figure 5.2 Example showing recommended (a) and incorrect (b) overlap between images: The red dotted box in (a) and (b) show overlap region between images 1 and 2.

TABLE 5.1
Wrong image collection layouts

Index	Practice	Layout	Reason
L1	Wrong		Sparse collection with not enough overlap
L2	Wrong		Irregular distance between the cameras and the wall
L3	Wrong		Insufficient overlap at the sides of the wall
L4	Wrong		Collection of too many photos in a certain region
L5	Wrong		Varying camera's translational movement, not rotational variation

Note that these layouts are illustrated using a set of parallel images but sets of right and left oblique images are also applicable.



Figure 5.3 Fit the wall in the vertical direction with some margin, as demonstrated in (a). Image (b) does not have enough margin at the top. In image (c), only a small portion of the image area contains the wall.

- oblique images* in four directions (4~5 images in each direction) will be helpful to reduce the distortion of the final orthophoto although they are not utilized to generate the final orthophoto (see Figures 5.7 and 5.8).
- GA4. It is highly recommended that each image contain a portion of the border of the sidewalk with enough margin (see Figure 5.7, and L3 in Table 5.1).
- GA5. For highest quality results, it is recommended to use a consumer grade compact camera, DSLR camera, or an iPhone 6s. Cameras used in the other brands of smartphones may produce a large distortion in the images, causing large measurement errors.
- GA6. Recommended settings for the DSLR camera are: (1) zoom should be stable, (2) fixed (manual) focal length is recommended, (3) stabilization settings should be off, and (4) shutter/aperture/ISO should be on automatic (the settings to use with the iPhone 6s are described in Chapter 5.5).
- GA7. Maximize the height of your camera (for instance, by stretching out the selfie stick/pole) to cover a larger area with fewer number of images.
- GA8. Use a large inclination with the selfie stick so that your feet are not included in any of the images.
- GA9. Dynamically changing shadows generated by users and/or equipment must not be visible in the images. Please do not take a picture with the sun directly behind you and the camera.



Figure 5.4 (Wrong) Sample image collection: violating GW2, GW3, and L2.

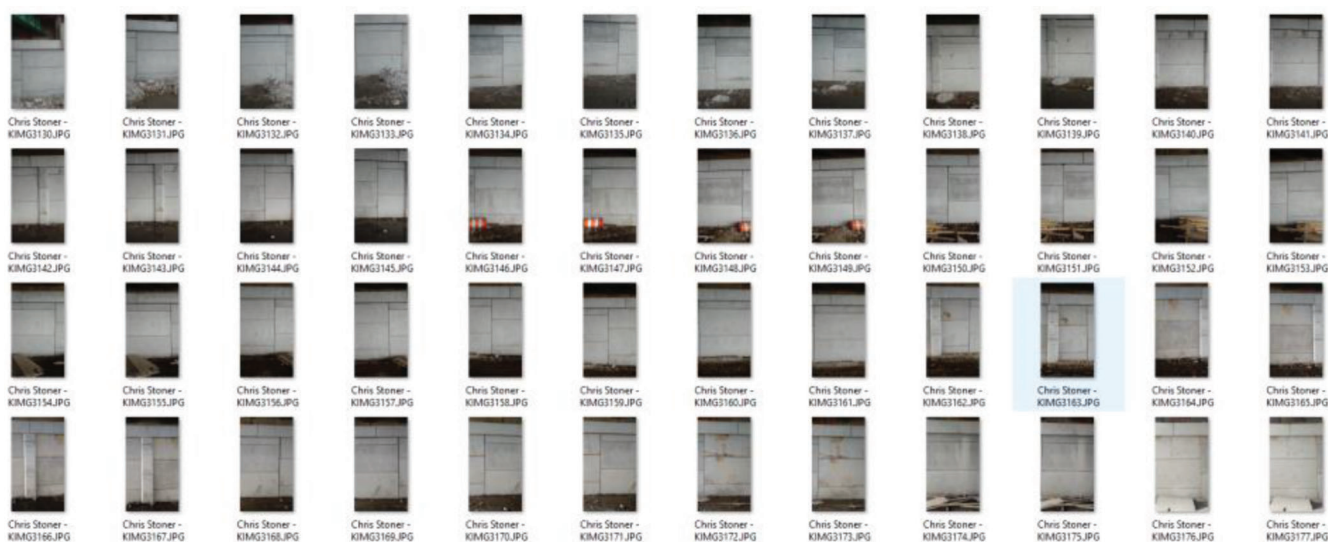


Figure 5.5 (Wrong) Sample image collection: violating GW1 and L1.

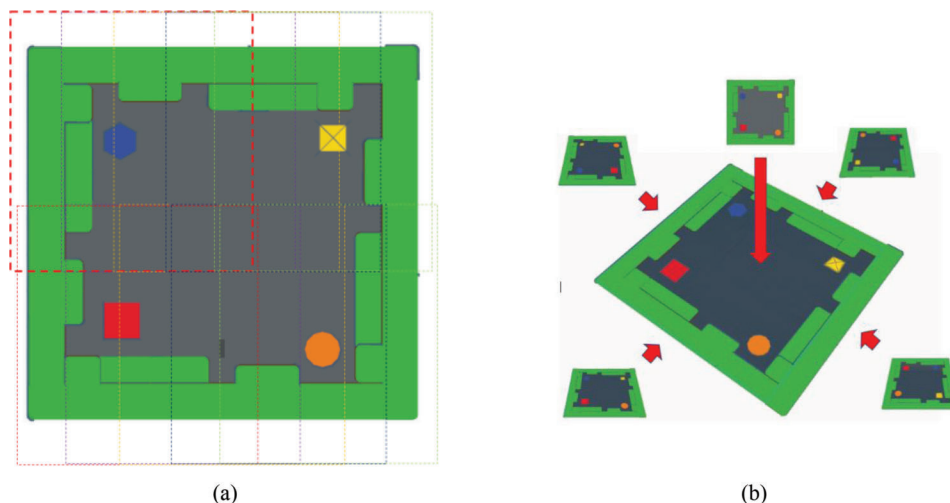


Figure 5.6 Images should have sufficient overlap and cover whole surface including boundaries with margins: (a) Sufficient overlap between images (rectangular with dash line) and (b) Sample of parallel and oblique views.



Figure 5.7 (Wrong) Sample image collection: violating GW9.



Figure 5.8 (Wrong) Sample image collection: violating GW9 (Combination of static shadow, shadow of fence, and moving shadow, shadow of shaking trees).

5.2 Calibration Strategy

Calibration is another important step that heavily influences the accuracy of measurements. Improper calibration would lead to the erroneous measurement of *each and every item* on the orthophoto. Based on lessons learned from this process on site, common mistakes include: (1) inaccurate ground-truth measurement, (2) measured locations used for calibration are not clearly visible on the orthophotos, and (3) short calibration distance. The main rule to minimize errors is to use two or three relatively long ground-truth measurements at the site for calibration. Using long calibration distances is best because there is less influence due to small measurement errors (a $\frac{1}{4}$ " error in a measurement is large for a 6" distance, but is not large for a 6' distance). Using a long distance for calibration provides an unbiased estimate of the true calibration scaling, and makes measurements insensitive to errors

generated from imprecise measurement or point selection on the orthophoto. In addition, erroneous estimation of the projection plane can be mitigated by using different calibration locations that are far away from each other on the orthophoto. However, *too many calibration measurements do not serve to improve the accuracy of the images and measurements and are not worth the additional time and effort on site needed for such manual measurements.*

General Guidelines

1. At the site, two locations (points) on the wall are chosen, which are clearly visible with bare eyes and accurately localized on the images.
2. An object (e.g., yardstick, measuring tape) with known dimension can be used for this process. However, it is typically too short to accurately calibrate an image for a large site.
3. It may be desirable in some cases to attach large circular marker/stickers (called as a fiducial marker) at a couple

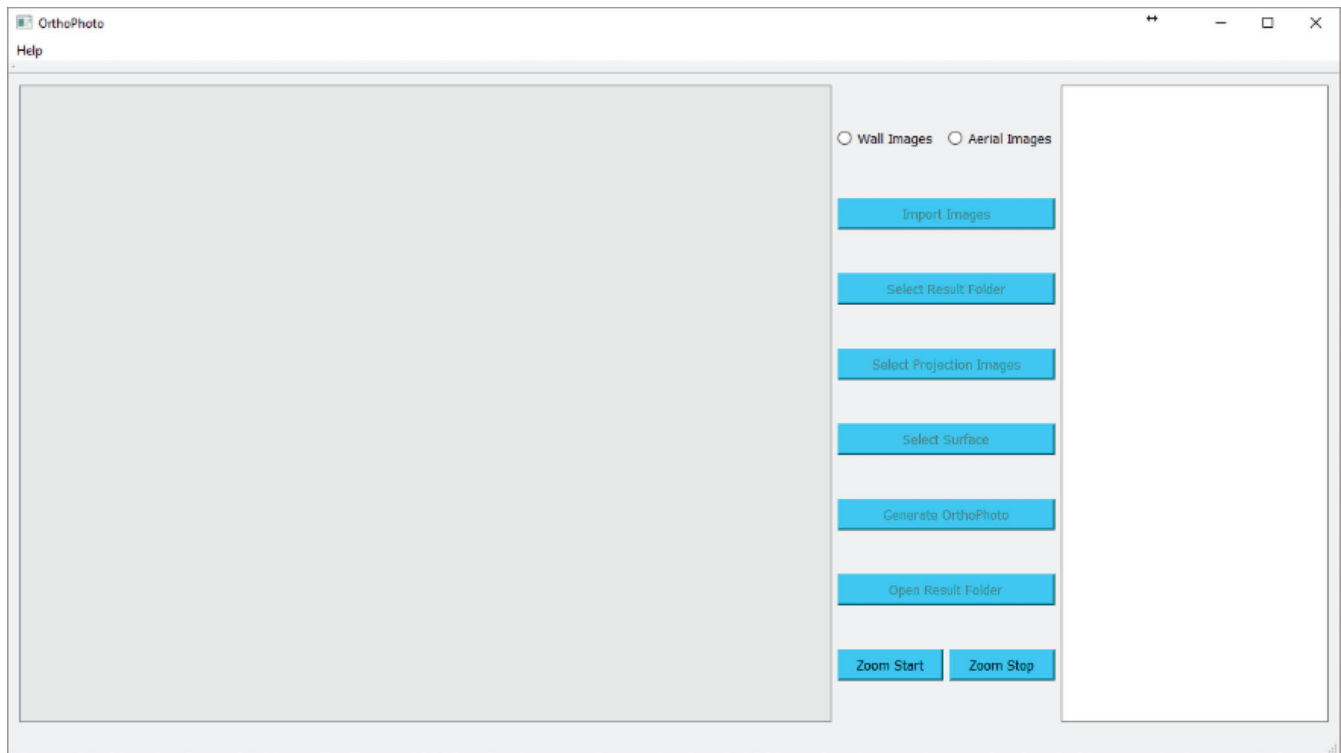


Figure 5.9 Layout of the Orthophoto Generation Tool.

- of selected points to designate the calibration points used (printable fiducial markers in Appendix A).
- During image collection, care should be taken to properly capture the areas that include the calibration points. It is acceptable to take one or two extra pictures at similar places.
 - Using between one and three calibration distances is recommended. The best practice is to have both horizontal and vertical lines for calibration.

5.3 Orthophoto Generation Tool

The Orthophoto Generation Tool performs the process of converting a set of many images collected at a site into one large and high-resolution view of the pay items of interest. This tool runs independently, and user-input is only required for two steps, including: (1) selecting images parallel to the pay item, and (2) selecting the flat area (the plane) of interest in which the pay items to be measured are located. This tool will then stitch and blend the images based using the parameters that are defined internally in the code. These parameters were set specifically the uses of interest in this project. Thus, to be successful in orthophoto generation, users must strictly follow the image collection procedures and guidelines defined herein (see Chapter 5.1). **Before using the tool for the first time in a computer, it is required to run the *setup.exe* file found in the same directory as the tool.** This file installs the windows C++ redistributable package. Administrative access may or may not be required for this step. If the computer has the required C++ libraries, the setup may report a failure,

but *this error can be ignored as the tool will function correctly*. The details of the tool are addressed below.

The layout of the Orthophoto Generation Tool interface is shown in Figure 5.9. The available functionalities of the tool, and their usage are explained below.

- Select Image Type:** Choose a site type of *Wall Images* or *Aerial Images*.
- Import Images:** After clicking the *Import Images* button in the menu bar on the top, navigate to the folder where the images are. Then, press OK. **Note that your images in the folder are not visible when you select the folder.**
- Select Results Folder:** Select the folder to save the results and press OK.
- Select Projection Images:** Opens the folder containing input images. Select images that are parallel to the pay item under consideration. Avoid images that view the pay items with a large angle (see Chapter 5.5). After selecting the images click OK.
- Select Surface:** Opens the folder containing the input images. Select one image that will be used to define the surface, or plane, containing the pay items to be measured, and to which the final image will be projected. Click OK. When the selected image appears in the viewer, left click on the surface to select several points that lie on that surface, **in order** (clockwise or counter-clockwise). Note that you should select at least three points along the surface and be sure that no out-of-plane objects or areas are included.
- Generate Orthophoto:** Generate the final orthophoto image. This step will require processing time, and the amount of time is dependent on the number of images to be used.
- Open Results Folder:** Open the folder containing the orthophoto image.

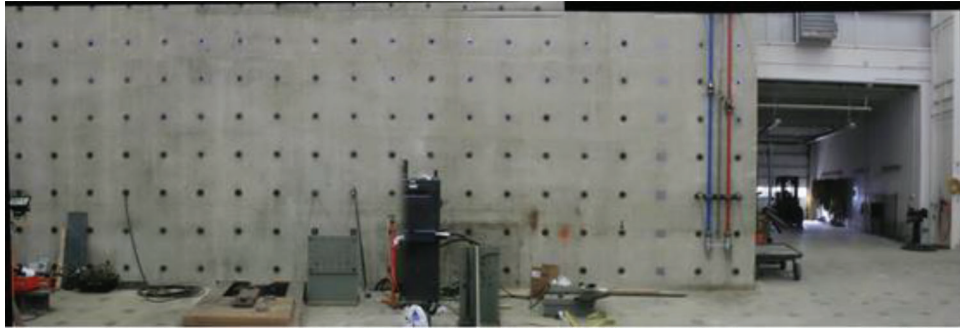


Figure 5.10 Sample orthophoto (6,853 x 2,768 pixels) generated from 6 images (< 2 min using high-performance laptop in Chapter 6.1).



Figure 5.11 Sample orthophoto (7,997 x 2,839 pixels) generated from 53 images (< 30 min using high-performance laptop in Chapter 6.1).

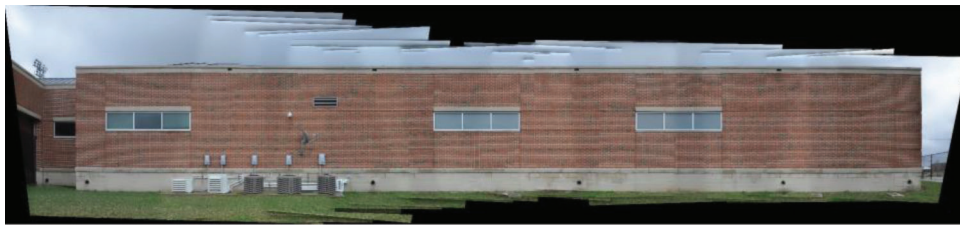


Figure 5.12 Sample orthophoto (7,997 x 1,858 pixels) generated from 59 images (< 35 min using high-performance laptop in Chapter 6.1).

8. **Zoom Function:** Use **Zoom Start** and **Zoom Stop** buttons to start and stop the zoom functionality respectively. After clicking the Start button, hover over the region to be zoomed and zoom using the mouse wheel. To exit the zoom mode, left click on Stop button. **It is necessary to click the Stop button after performing the zoom operation.**

The final orthophoto is saved in the selected folder. Depending on the number of images and performance of the computer, this step may take a few minutes to several hours (see Chapter 6.1). Since the program utilizes a large amount of the CPU resources, users may not use the computer for normal activities during this processing. **It is best to run larger image sets overnight.** Samples of high quality results are shown in Figures 5.10, 5.11 and 5.12.

5.4 Graphical Measurement Tool

The Graphical Measurement Tool is designed to conduct several measurements on an orthophoto constructed by the Orthophoto Generation Tool, shown in Figure 5.13.

The tool has been customized based on the user comments/feedback received from SAC members. Several iterations of internal testing were conducted before bringing the tools, in prototype form, to the SAC. The tool is quite intuitive, and can be used in a Windows environment without installation. Details on the functionalities of this tool, and their usage are explained below.

1. **Load Orthophoto:** Click on **Load Image** under the **File** tab in the menu bar. After selecting the **Load Image** function, navigate to the folder where the orthoimage containing the pay items to be measured is located, and select the image file. When done selecting, press OK. *Note that a regular image cannot be used for the measurement.*
2. **Save:** Click on **Save** under the **File** tab in the menu bar. Select the folder to save the results and press OK. The final image will be saved as a PDF file, and the log will be saved as a CSV file.
3. **Crop:** Click on **Crop** under the **Edit** tab in the menu bar. First left click at the top left corner of the region you want to crop. Hold the mouse and move to the bottom right corner of the region. A magenta dashed box will

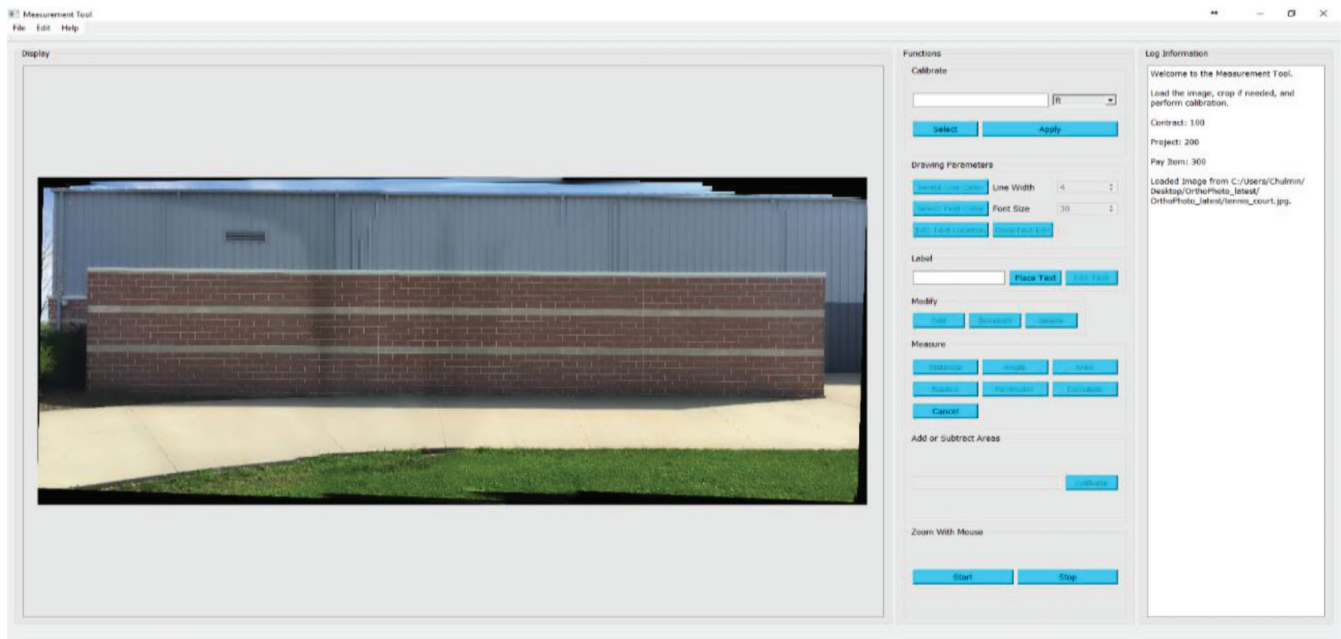


Figure 5.13 Layout of the Graphical Measurement Tool.

- appear around the region. Release the mouse, and a window will appear asking if the region selected is correct or not. If correct, press OK and the selected region will be cropped and will appear in its modified form in the window. If it is not correct, click cancel and repeat the steps. *Note that cropping should be performed before making any measurements or the measurements will be lost.*
4. **Calibrate:** Click on the **Select** button. Select two points in the image such that the distance between them is known. After the two points are selected, enter the known distance in the text field. Click on **Apply** to calculate the calibration ratio. This process can be repeated many times, and the average of all calibration ratios provided will be used. It is important to provide all calibration values using a single unit. For example, if a calibration was performed with the unit selected as “ft,” then further calibrations should use “ft” as a unit and not “yd.” Select the preferred unit when entering the first calibration distance. Confirmation is requested when the **Apply** button is pressed. If the points selected are not satisfactory, the user should press **No** in the confirmation window to cancel the current calibration and delete the calibration line manually. The edit functionality may be used for accurate placement of the points.
5. **Drawing Parameters:** Use functions in this section to choose the line width, line color, font size, and text color for measurements. The user may want to customize the colors based on the background colors present, or on types of measurements made. Make these selections before performing the measurement.
 - a. **Select Line Parameters:** Click on the **Select Line Color** button to select a color from the color palette. Select the width of the line from the drop-down menu.
 - b. **Select Text Parameters:** Click on the **Select Text Color** button to select a color from the color palette.
- c. **Edit Text Location:** First select the item whose text needs to be updated by clicking on it with the mouse. The item will be highlighted. Next, click on the **Edit Text Location** button. Then click and hold (do not release the mouse) near the first letter of the text within the highlighted box. A small black circle will appear. Drag the circle to the new desired text location, and release the mouse. Press **Done Text Edit** button after finishing the editing.
6. **Label:** To add labels (to mark single item features, such as signs) to the image and edit the labels.
 - a. **Place Text:** Enter the label to be added in the text field, and then click the **Place Text** button. Click on location in the image where the label needs to be placed.
 - b. **Edit Text:** Click on the **Edit Text** button and then click on the label that needs to be edited. A new window will pop up asking for the new label. Enter the new label in the space provided, and click OK.
7. **Measure:** This section contains the functions needed to make various measurements on the image.
 - a. **Distance:** Click on the **Distance** button, and select two points on the image that span the distance measurement to be made. Click on the **Calculate** button and the distance between the two points will be calculated. A line is drawn between the points, and the distance appears next to the line.
 - b. **Angle:** Click on the **Angle** button. Select three points on the image. Click on the **Calculate** button and the angle formed by the lines between first and second point, and between the second and third point is calculated. The two lines are drawn, and the measured angle is displayed in degrees next to the shape.

- c. **Area:** Click on the *Area* button. Select points defining the area to be measured in a set order, either clockwise or counter-clockwise. Click on the *Calculate* button after selecting all the points defining the polygon. The area enclosed by the polygon formed by the points is calculated. The polygon and the area are displayed.
 - d. **Radius:** Click on the *Radius* button. Select two points defining the diameter of a circle. Click on the *Calculate* button, and the radius of the circle is measured. Both the circle and the radius measurement are displayed.
 - e. **Perimeter:** Click on the *Perimeter* button. Select points beginning at one endpoint of the perimeter to be measured. Use a set order, either clockwise or counter-clockwise. Click on the *Calculate* button after selecting all the points defining the perimeter. The perimeter of the polygon formed by the points is calculated. The polygon and the perimeter are displayed.
 - f. **Cancel:** Will cancel the current operation. For Distance, Angle, Radius, and Calibration functions, the *Cancel* button should be pressed before selecting a point. After a point is selected, the delete button should be used to remove invalid measurements. For Area and Perimeter functions, the Cancel button can be used after selecting points as well. A window will appear asking for confirmation.
8. **Modify:** This section contains the functions needed to edit or delete the measurements made on the image.
 - a. **Edit Measurements:** Click on the *Edit* button. Select the measurement object (Distance, Perimeter, Angle, Area, etc) to be edited on the orthophoto. The object will be highlighted. Now click and hold (do not release the mouse) near a point in the object highlighted using the “X” symbol. A circle will appear around the “X” symbol. Only if the circle appears, drag the mouse to the new position and release the mouse. The point will be moved, and the object and associated measurement will be updated. Repeat this for the points to be edited, and click *DoneEdit* button when finished. It is recommended to edit one object at a time.
 - b. **Delete Measurements:** Select measurement object(s) on the image and click the *Delete* button. A window will pop up asking for confirmation. Press OK to delete the selected object.
 9. **Adding or Subtracting Areas:** The areas measured on the image can be referenced using the letter “A” followed by

the number as displayed. To measure a combination of areas, the areas can be added or subtracted by entering the respective equation in the text field provided. An example of a valid equation is as follows: A1+A2-A3. Note that **no spaces** are allowed in the equation. It is important to maintain this syntax, or else the calculation will not work and may display garbage. After entering the equation click on the *Evaluate* button. The equation and the result will be displayed in the log window.

10. **Zoom with Mouse:** To activate the zoom functionality click on the *Start* button under Zoom with Mouse. Hover over the region to be zoomed, and then zoom in using the mouse wheel. To exit the zoom mode, click on the *Stop* button under Zoom with Mouse.

5.5 Step-by-Step Procedure

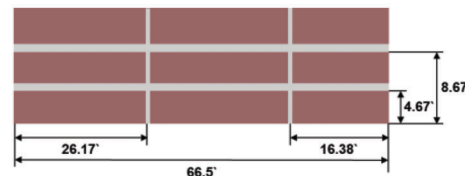
5.5.1 Example 1: Measurement of a Storage Wall Using iPhone 6s

In our discussions with the SAC members, it was noted that they prefer collecting images using an iPhone 6s rather than DSLR cameras. Here, we illustrate a step-by-step procedure to follow, from data collection to measurements, using the tool package developed. The wall selected for this case is a red-brick storage wall, shown in Figure 5.14(a). The dimensions of the wall were manually measured using a measuring tape (see these in Figure 5.14(b)).

Step 1: Camera Setup (iPhone 6s). The iPhone 6s takes good quality photos and has a user-friendly interface to easily collect suitable photos on the job site. Although a high-resolution DSLR camera would typically produce the most reliable results, the iPhone 6s also produces acceptable accuracy. Figure 5.15 shows how to perform the initial setup before capturing images using the iPhone 6s. Use of the grid in the viewer can assist users to capture images that are parallel to the wall. The function can be turned on in Settings>Photos & Camera>Grid. The HDR function, which automatically changes the dynamic range of the photos is for taking more colorful photos with enhanced details. *However, this function should be turned off for image collection* (Figure 5.15(d)). The iPhone 6s has a fast shutter so that users can take pictures by walking along



(a)



(b)

Figure 5.14 Test site: (a) Photograph of the storage wall, and (b) Manual measurement results using a measuring tape.

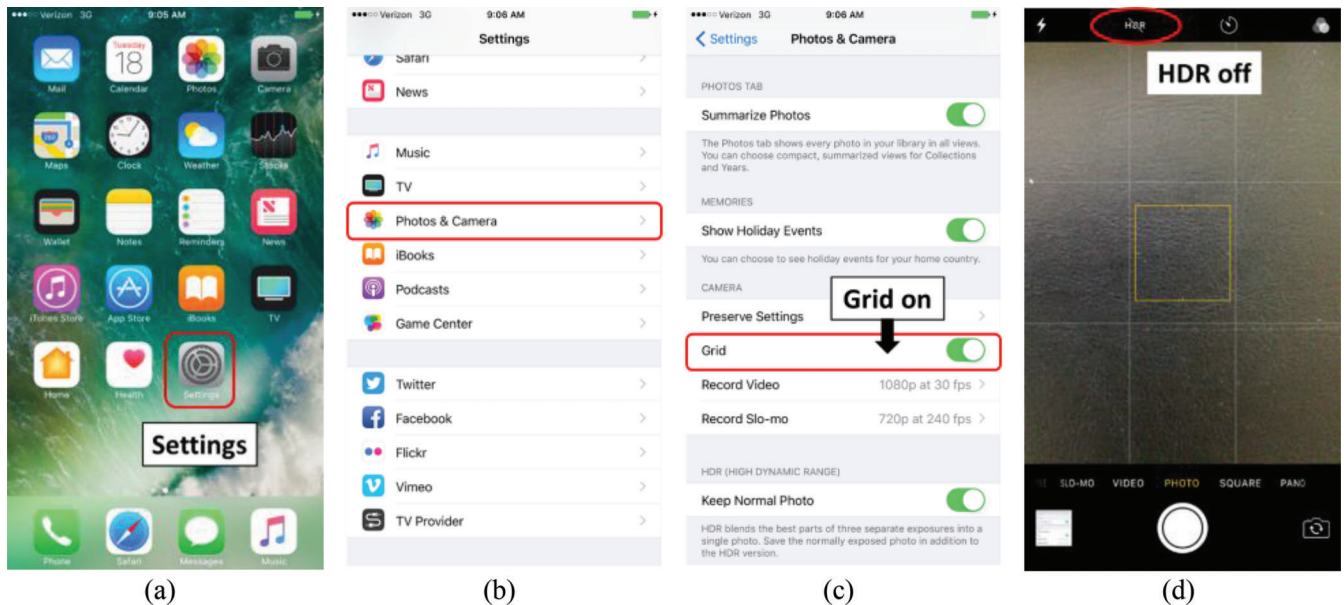


Figure 5.15 Setting iPhone 6s for image collection: (a) Settings, (b) Photo & Camera, (c) Grid on, and (d) HDR off.

the wall without pausing. The best practice is to take a photo every one or two steps. Note that as mentioned in the guideline, *the zoom function must not be utilized*.

Step 2: Image Collection. First, determine a suitable and safe distance for taking photos of the wall. Recall that the vertical height of the wall should be fully included, and there should also be some margin at the top and bottom in each photo. When taking photos, make the best effort to maintain an image plane that is parallel to the wall plane. This step will reduce the inclusion of out-of-plane components in the final orthophoto. The photos must be captured at regular intervals by moving one or two steps between photos. The first photo is collected from a location where there is enough margin at the left or right edge of the wall (see GW7 and L3 in Chapter 5.1). In Figure 5.16, the set of images shown inside the red box represents an appropriate set of parallel images.

Then, right and left oblique images are captured in a similar way. The images must be taken with roughly regular spacing, as done when collecting the parallel images. The oblique images also start from enough margin at the both ends. In Figure 5.16, the sample images in the blue and green boxes are captured with such angles. The number of images should be balanced with similar coverage in these three sets (parallel and two oblique images). In Appendix B, more sample sets of images collected following the guidelines are shown.

Step 3: Orthophoto Generation. A user first starts the Orthophoto Generation Tool by double-clicking on the file named OrthoPhoto.exe in the folder that you designated. **The folders of the tool and images and the names of the image files should be assigned where their paths have no empty space.** For example, “MSE wall” or

“image 1.jpg” produces an error from the Orthophoto Generation Tool. Then, when prompted, enter the contract, project and pay item numbers in each pop-up windows. The blue buttons located to the right of the tool are executed in order. If you fail to complete a step in this sequence, you cannot move to the next step.

As mentioned in Chapter 5.3, the windows C++ redistributable package must be installed on the computer. Run the *setup.exe* file found in the same directory as the tool. Administrative may be required for this step.

First, click **Wall Images** option button. Then, select the images to be combined into an orthophoto. Click on the **Import Images** button, and navigate to the folder where the images are located. Select the folder where images present. When done selecting the folder, press OK. Second, click **Select Result Folder** to designate the folder where you will save the orthophoto, and press OK as in Figure 5.17(b). Any folder can be selected. Third, click **Select Projection Images** to assign the images that are used for projection and blending in Figure 5.17(c). Here the images inside the orange dotted box in Figure 5.16 are selected by holding down the shift button on the keyboard. Fourth, click **Select Surface**, and select an image that has a clear view of the planar wall surface where you will make your measurements. Note that the best image for this surface selection: (1) is parallel to the wall, and (3) has no blur and is not too bright or too dark. As shown in Figure 5.17(d) (orange arrows), at least four points on the planar surface to be measured should be selected, and the polygon created by connecting these points must include only regions that are within this plane. Selecting a larger region, while avoiding the inclusion of out-of-plane components in that region, improves the accuracy of the measurements made with the orthophoto. Use the **Zoom Mouse Start**



Figure 5.16 Images collected from the storage wall.

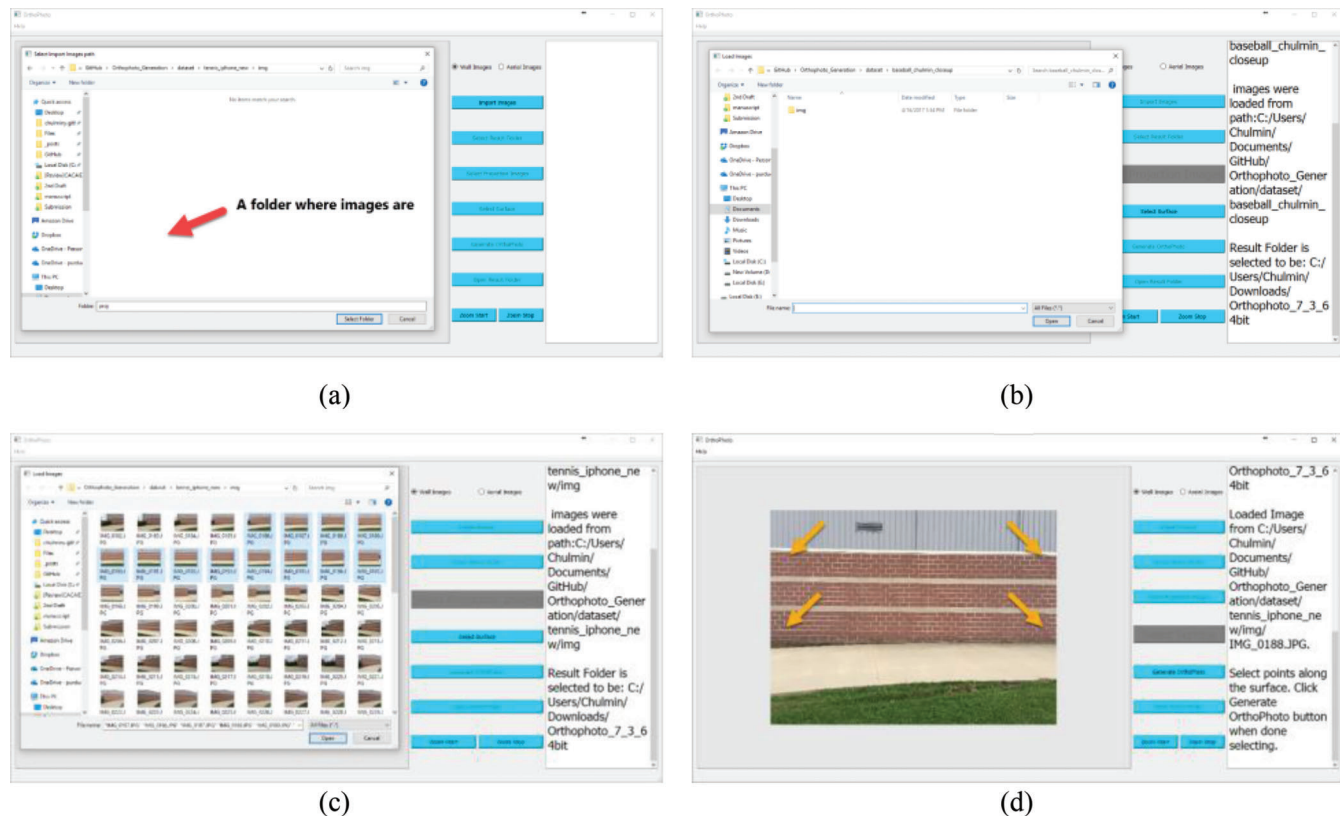


Figure 5.17 Steps for the Orthophoto Generation Tool.

and **Zoom Mouse Stop** buttons to adjust the size to select points. Finally, when you are done selecting points along the surface, click the **Generate Orthophoto** button.

It will take a few minutes to a few hours to complete the computations needed for the orthophoto. Once the processing is finished, the final orthophoto will



Figure 5.18 Measurement results using the Graphical Measurement Tool.

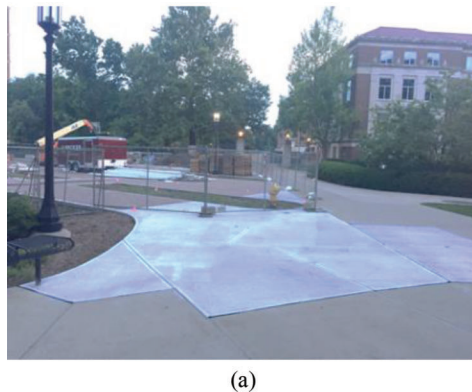


Figure 5.19 Test site example of sidewalk: (a) Photograph of the sidewalk, and (b) Manual measurement results using a measuring tape.

be placed in the folder assigned. You may also simply click **Open Result Folder**.

Step 4: Measurement. Figure 5.18 shows the Graphical Measurement Tool with a selected measurement image. Here, we illustrate how to make typical measurements. After starting the measurement tool (double click on measurementTool.exe) in the designated folder, follow the initial steps performed previously with the Orthophoto Generation Tool. When prompted, enter the contract, project and pay item numbers in each of the pop-up windows. On the menu bar, click **File>load** image, and load the orthophoto image constructed in the previous step. Because orthophoto images often include irrelevant areas that are not needed for actual measurements, it may be best to crop the irrelevant areas. Click **Start** in **Zoom With Mouse** and move the image around until the orthophoto fits nicely in the image viewer. Then, click the **Stop** button to exit the zoom mode, and enable the use of the other functions again. To crop out unnecessary parts, go to the menu bar, and click **Edit>Crop**. Draw a rectangle around just the portion of the image that you want to keep.

Next, the orthophoto is calibrated to a physical scale using known distance(s). First, select the units (either “ft” or “yds”). Enter the length of a known distance in the text field under **Calibrate**. Here, in the example, we use the bottom left horizontal line for calibration (26.17’ in Figure 5.14(b) and the purple line in Figure 5.18).

After typing 26.17 in the text field, click **Select** and choose the two end points for the line. Then, click **Apply**.

After completing the calibration process, distances of interest can be measured. The line width, line color, font size, and text color can be selected, but they must be changed prior to making each measurement. Four lines, including two vertical and horizontal lines (D3 and D4, and D1 and D2 in Figure 5.18), are measured in this example. Sample measurements are shown in Figure 5.15. To save the measurement results, on the menu bar, click **File>Save**. Select the folder where you want to save the results. Then, press OK. The filename will automatically be generated using the contract, project, and pay item numbers entered by the user. The image with the measurements will be saved as a PDF file, and the text in the log will automatically be saved using CSV format.

5.5.2 Example 2: Measurement of a Sidewalk Using iPhone 6s

We illustrate a step-by-step procedure to construct an aerial orthophoto. The selected site is a sidewalk having curved and straight concrete segments. Overall procedures for constructing “wall” and “aerial” orthophotos are similar to each other. Thus, here we highlight the differences in their procedures. The test site and its manual measurements are shown in Figure 5.19.

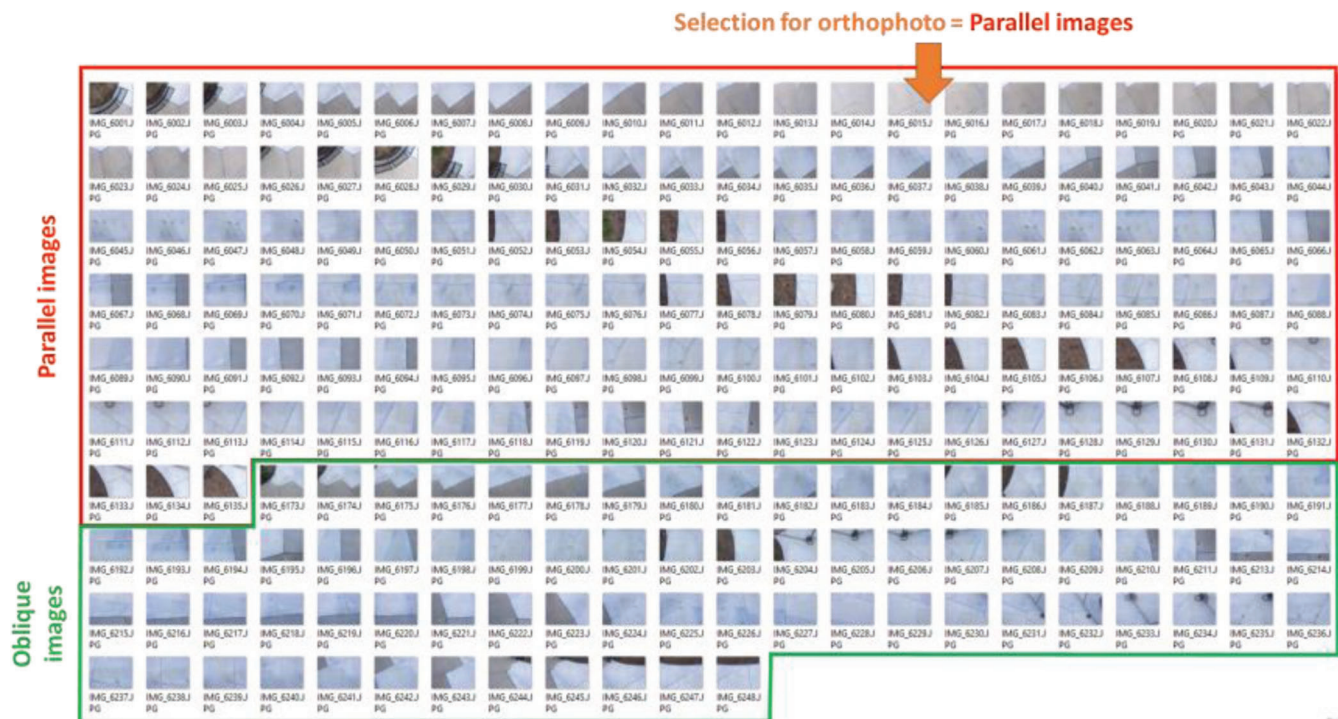


Figure 5.20 Images collected from the sidewalk.

Full video guidelines for this example are available for viewing and download here:

- How to take aerial images: <https://doi.org/10.4231/R73B5XBK>
- How to use the Graphical Measurement Tool: <https://doi.org/10.4231/R7ZK5DV8>
- How to use the Orthophoto Generation Tool: <https://doi.org/10.4231/R7TT4P4Z>

Step 1: Camera Setup (iPhone 6s). The settings for the iPhone 6s are the same with the one in example 1. Once the users set up the phone, the selfie stick must be used for this application to cover large areas with a large overlap between images. Users pair the phone with the selfie stick via Bluetooth to a remote picture taking.

Step 2: Image Collection. As mentioned in Chapter 5.1, images must be collected with sufficient overlap in both horizontal and vertical direction. After pairing the phone with the selfie stick, maximize the length of a selfie stick's arm and take photos from an elevated position. When taking photos, make the best effort to maintain an image plane that is parallel to the ground plane. The photos must be captured at regular intervals by moving one or two steps between photos in both vertical and horizontal direction. Once the parallel image collection is finished, a couple of right and left oblique images should be captured (please see GA3 in Chapter 5.1). In Figure 5.20, the sample images shown in the blue and green boxes are captured with such angles. **Different than in the wall example, it is not easy to visually recognize the parallel and oblique images.**

Thus, users must remember or record when they begin to collect the oblique images.

Step 3: Orthophoto Generation. Click **Aerial Images** option button and then, the rest of the process is the same with the one in example 1. For the aerial images, **the users do not need to conduct Select Surface.** Thus, this button is inactive.

6. PIM TOOL EVALUATION

6.1 Speed

Considering the various steps to perform, from image collection to measurement, the most time-consuming step is usually to create the orthophoto from a collection of images. In general, the processing time for the orthophoto generation is highly determined by the performance of the CPU. Since the OpenMVG library supports parallel processing using OpenMP as default, the use of multicore high-performance CPUs can dramatically reduce computation time. While the program is running, the program automatically use all CPU cores in a computer. Thus, low-grade computers, which are not designed for numerical computation, must not be used for normal activities during this processing. The recommend system requirement for use of the Orthophoto Generation Tool is **Windows 10, 64 bits, Quad-core CPU (Intel i5 /i7/ Xeon), SSD hard drive, and 4GB RAM.**

In this subchapter, required computation speeds are evaluated using different computers. This information is provided so that users may estimate the time needed for processing depending on the specifications of the

TABLE 6.1
List of tested computers

Computer Name	CPU	RAM	OS	Storage Type
Tablet PC	Intel Core™ M-5Y51	8 GB	Windows 10	SSD
High-performance laptop	Intel Xeon CPU E3-1505M	16 GB	Windows 10	SSD
Normal Desktop	Intel Core i7-3770	8 GB	Windows 10	HDD
Normal laptop	Intel Core i5-6200	8 GB	Windows 10	SSD

TABLE 6.2
Image sets used for the evaluation study

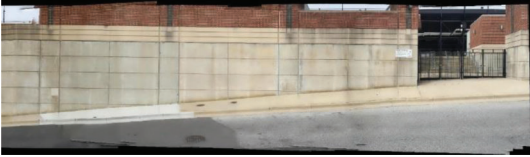



Image Set Name	# of Images	Orthophoto
Stadium wall	148	
Retaining wall	205	
Stadium entrance	113	
Baseball field entrance	89	

TABLE 6.3
Comparison of time required for orthophoto construction

	Tablet PC	High-Performance Laptop	Normal Laptop	Normal Desktop
Stadium wall	270 minutes	61 minutes	135 minutes	55 minutes
Retaining wall	305 minutes	125 minutes	300 minutes	120 minutes
Stadium entrance	120 minutes	63 minutes	171 minutes	59 minutes
Baseball field entrance	170 minutes	55 minutes	40 minutes	47 minutes

user's computer. Table 6.1 shows the computers used for this comparison study.

Data analysis from five different datasets, collected from a flat wall in different locations, are considered. All photos are taken with an iPhone 6s, as requested by SAC members. Table 6.2 shows the images used for this evaluation study (see Appendix B).

Table 6.3 shows a comparison of the required processing times on different computers. Unfortunately, the tablet PC currently used by INDOT does not meet the recommended system requirements. The tablet commonly used

by INDOT is 2~4 times slower than a typical laptop. This low performance is because the core-M processor is designed for a mobile PC, with very low power consumption and temperature. This CPU is targeted to a long battery life, but not high performance. Its processor is designed for light web browsing and word processing (it is comparable to an i3-processor). To save time, it is recommended to use an Intel i7 grade CPU for processing larger image sets. Note that the completion time is not always proportional to the number of images, but it is a reasonable way to estimate processing time.

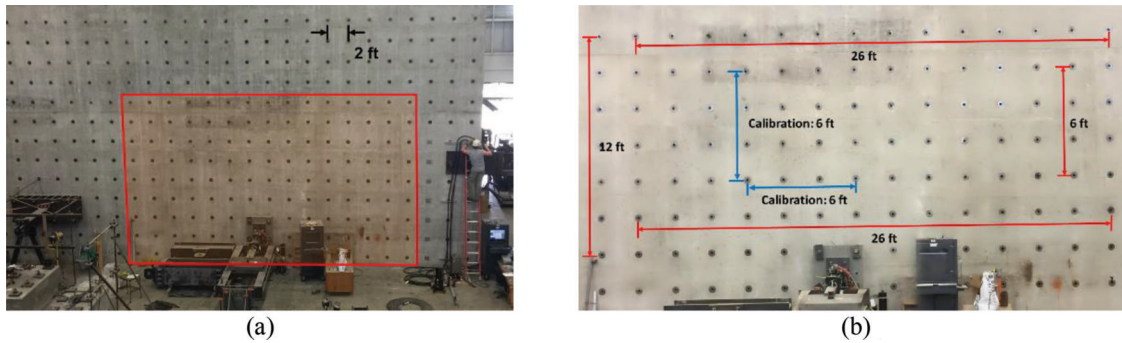


Figure 6.1 Test wall used for accuracy evaluation: (a) Evaluation region. Distances between bolt holes are 2 ft. (b) Target distances for comparison. Distances in red are compared to orthophoto obtained by five image sets which calibrated by distances in blue.

TABLE 6.4
Comparison of accuracy computed from several orthophotos generated with different image sets

Set	# of Images	Orthophoto with Measurements	Mean Accuracy
#1	62		99.8%
#2	85		99.8%
#3	79		99.8%
#4	82		99.9%

6.2 Accuracy and Repeatability

At the beginning of Chapter 5, it was explained that the accuracy of measurement is controlled by (1) how the images are collected, and (2) how measurements are made with the orthophoto. However, by strictly following the guidelines for using the Orthophoto Generation Tool and Graphical Measurement Tool (provided in Chapter 5) the difference between measurements made using these tools, and ground-truth measurements, is insignificant. Here, a quantitative evaluation of the variability and accuracy of the tool is provided using known collections of image sets.

We study the accuracy and variability in the measurement results obtained with different image sets. Four different sets of images are collected independently from the large concrete wall shown in Figure 6.1(a). All data sets are collected while strictly following the guidelines, and while using an iPhone 6s. This wall has a grid of bolt holes with a regular spacing of 2 ft. Thus, ground-truth distances are known, and can readily be compared with the results from the tool. Table 6.4 describes the number of images collected in each separate set, and shows the orthophoto that is generated with each set of images. As demonstrated in Figure 6.1(b), each image is used to measure four linear measurements (red lines). First each orthophoto is calibrated using the same two calibration distances, including a 6 ft vertical distance and a 6 ft horizontal distance (blue lines). Then the four different distances are measured for comparison. The accuracy of each orthophoto is described in Table 6.4. Regardless of the image set used, the variations of accuracy are less than 0.5%–1.5%, which is very small and acceptable in most actual measurement work.

7. SUMMARY

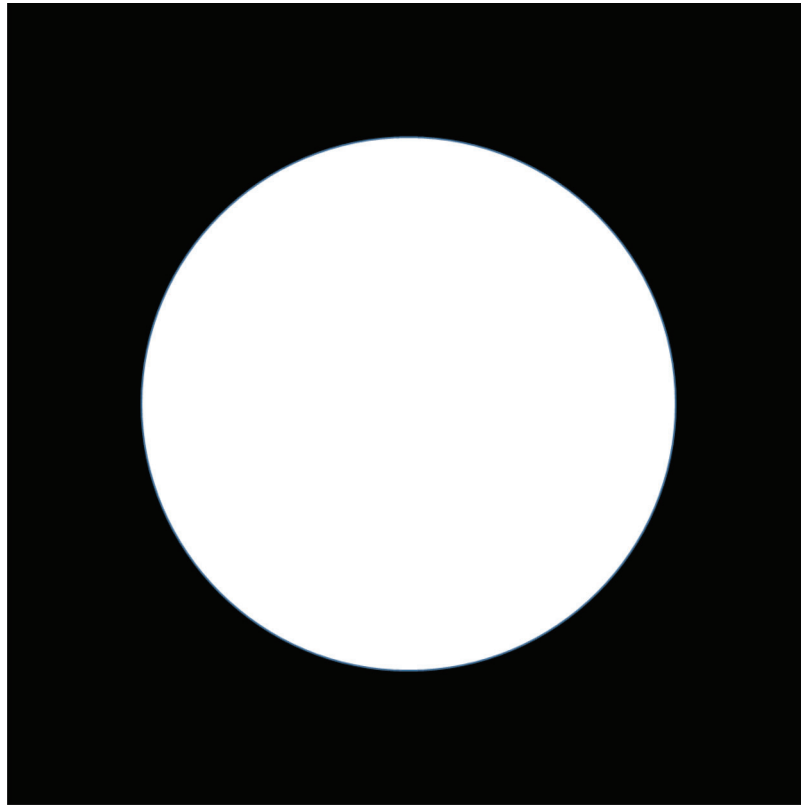
In this project, two customized software tools were developed and delivered for quantifying pay items. One tool generates orthophotos from a set of overlapping images captured for a planar surface by a hand-held camera or a UAV. The second tool provides a simple interface to measure the quantities of specific pay items at a site, and documents the results. The objective is to provide a user-friendly tool for quick and accurate measurement of pay items. User requirements were collected and documented through detailed discussions and observations of the INDOT procedures. The tool incorporates the actions that INDOT uses in the manual process, improving the rate of completing these tasks while significantly mitigating the associated risks to personnel safety. The tools have been developed in close cooperation with INDOT personnel. Many images of a job site can be combined to facilitate computations associated with measurement and documentation of the actual pay items placed. Distances, angles, areas, radii, and perimeters can be readily measured. The tool outputs the results in a format that allows INDOT to insert and archive those data into its chosen archiving system.

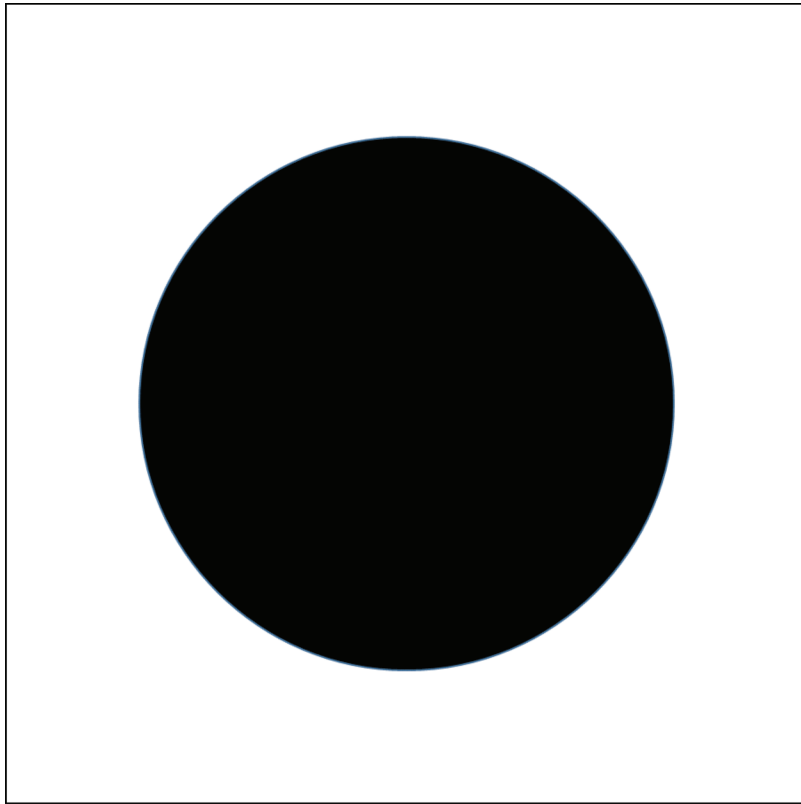
To use the tools properly and get accurate results, data collection is a critical step. Thus, a set of guidelines for data collection and calibration is provided to ensure robust and accurate performance of the automated, image-based tools. Additionally, the tool is compared to several commercial software packages that were designed to generate 2D image mosaics and/or 3D point clouds for very flexible applications. Because the tools developed in this project are customized to the needs of INDOT for pay item quantification, the capabilities of other more complex tools are not ideal for the intended purpose here.

REFERENCES

- Agisoft. (n.d.). Photoscan features—Professional edition. Retrieved October 30, 2015, from <http://www.agisoft.com/features/professional-edition/>
- ArcGIS. (n.d.a). Collector for ArcGIS. Retrieved November 5, 2015, from <http://doc.arcgis.com/en/collector/>
- ArcGIS. (n.d.b). Mapping without limits. Retrieved October 30, 2015, from <https://www.arcgis.com/features/>
- ArcPad. (n.d.). Mobile data application & field mapping software. Retrieved November 5, 2015, from <http://www.esri.com/software/arcgis/arcpad>
- Bentley Systems, Inc. (n.d.). Raster Manager in Microstation V8i [Software]. Retrieved October 30, 2015, from http://communities.bentley.com/products/microstation/w/microstation__wiki/4179
- Bradski, G., & Kaehler, A. (2008). *Learning OpenCV: Computer vision with the OpenCV library*. Sebastopol, CA: O'Reilly Media, Inc.
- Hexagon Geospatial. (n.d.). ERDAS IMAGINE. Retrieved October 30, 2015, from <http://www.hexagongeospatial.com/products/producer-suite/erdas-IMAGINE>
- Geosystems. (n.d.). IMAGINE UAV—Licenses. Retrieved November 2, 2015, from <http://www.imagine-uav.com/purchase.html>
- Google Maps. (n.d.). Retrieved June 7, 2015, from <https://www.google.com/maps>
- Hogan, S. (2015, July 22). ArcGIS for UAS [Blog post]. Retrieved October 20, 2015, from <http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=18431>
- Jahanshahi, M. R., Kelly, J. S., Masri, S. F., & Sukhatme, G. S. (2009). A survey and evaluation of promising approaches for automatic image-based defect detection of bridge structures. *Structure and Infrastructure Engineering*, 5(6), 455–486. <https://doi.org/10.1080/15732470801945930>
- Menci. (n.d.). Drone (APS) [Software]. Retrieved October 30, 2015, from <http://www.menci.com>
- Moulon, P., Monasse, P., & Marlet, R. (2012). Adaptive structure from motion with a contrario model estimation. In *Asian Conference on Computer Vision* (pp. 257–270). Berlin, Germany: Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-37447-0_20
- Photomodeler. (n.d.). PhotoModeler Scanner product overview. Retrieved October 30, 2015, from <http://www.photomodeler.com/products/scanner/default.html>
- Pix4D. (n.d.). Drone photogrammetry software for desktop + cloud + mobile. Retrieved October 30, 2015, from <https://pix4d.com>
- Yeum, C. M., & Dyke, S. J. (2015). Vision-based automated crack detection for bridge inspection. *Computer-Aided Civil and Infrastructure Engineering*, 30(10), 759–770. <https://doi.org/10.1111/mice.12141>

APPENDIX A: PRINTABLE FIDUCIAL MARKER

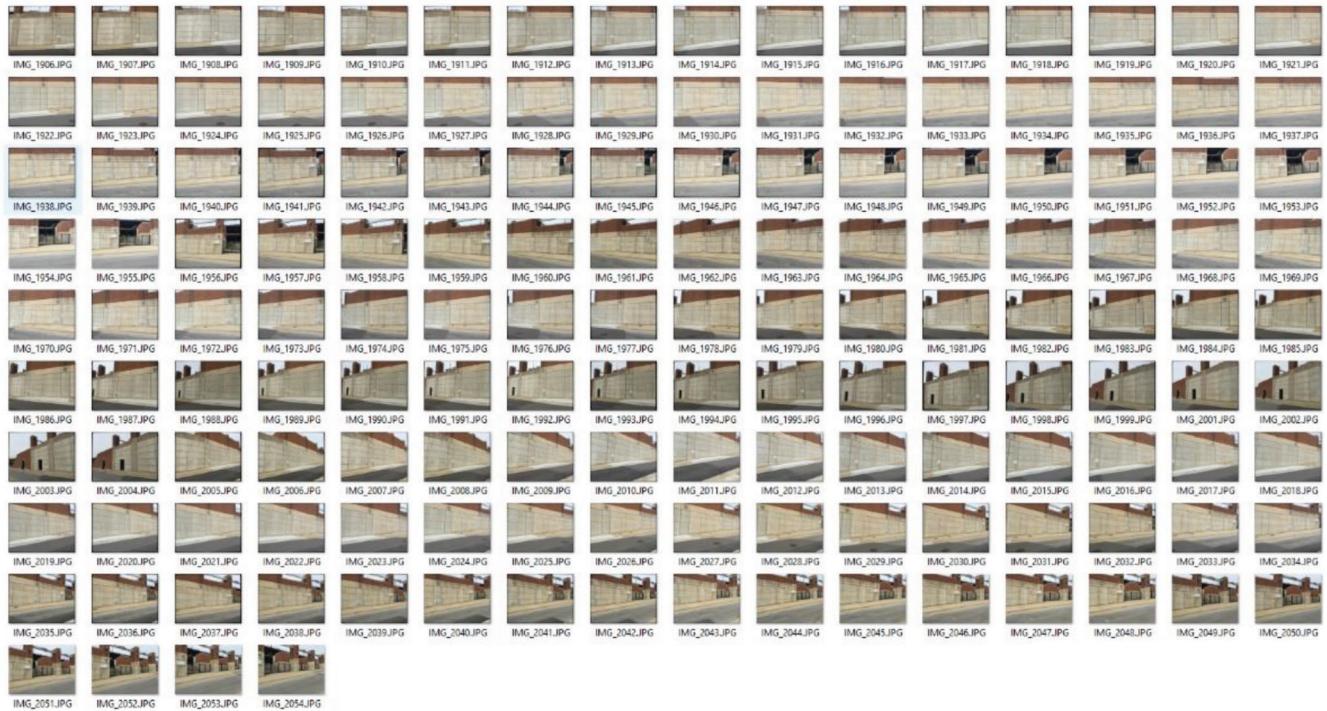




APPENDIX B: SAMPLE IMAGE SETS

B1. Stadium Wall

- # of images: 148
- Camera: iPhone 6s
- Collected images



- Orthophoto



B2. Retaining Wall

- # of images: 205
- Camera: iPhone 6s
- Collected images

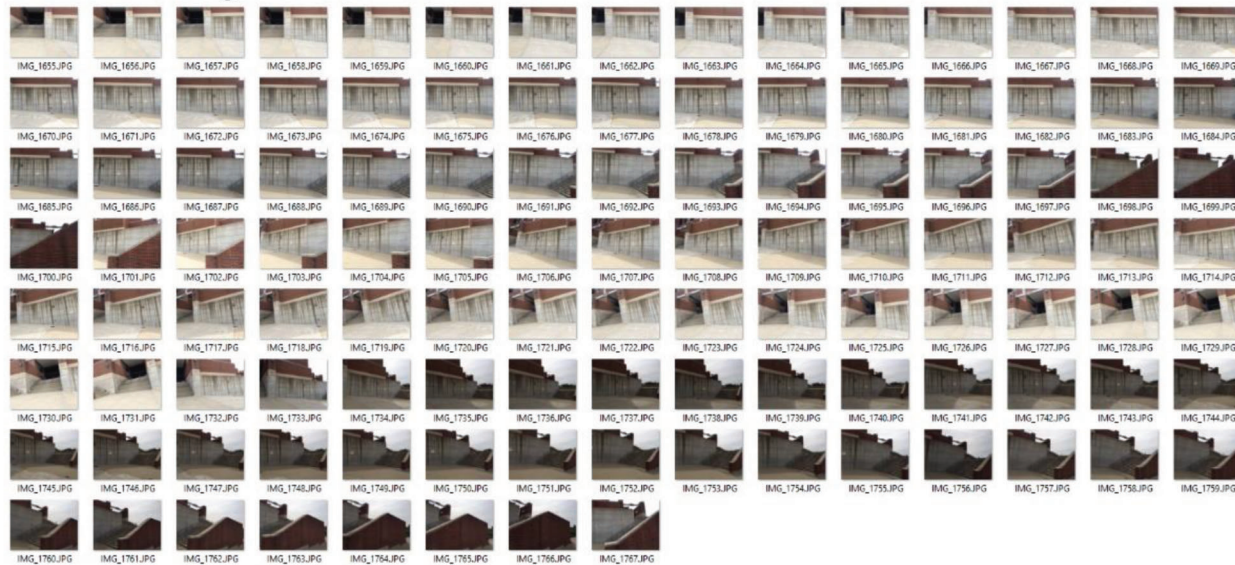


- Orthophoto



B3. Stadium Entrance

- # of images: 113
- Camera: iPhone 6s
- Collected images



- Orthophoto

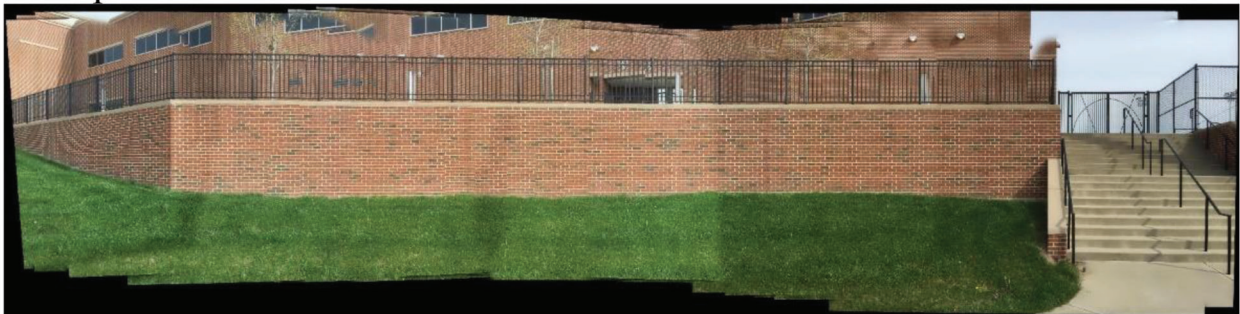


B4. Baseball Field Entrance

- # of images: 89
- Camera: iPhone 6s
- Collected images



- Orthophoto



About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1 — evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: <http://docs.lib.purdue.edu/jtrp>

Further information about JTRP and its current research program is available at: <http://www.purdue.edu/jtrp>

About This Report

An open access version of this publication is available online. This can be most easily located using the Digital Object Identifier (doi) listed below. Pre-2011 publications that include color illustrations are available online in color but are printed only in grayscale.

The recommended citation for this publication is:

Yeum, C. M., Mohan, A., Dyke, S. J., Jahanshahi, M., Choi, J., Zhao, Z., Lenjani, A., & Ramirez, J. A. (2017). *Image-based collection and measurements for construction pay items* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2017/10). West Lafayette, IN: Purdue University. <https://doi.org/10.5703/1288284316510>